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Technologies Enabling Smart Homes

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Abstract

Rapid advances in electronics integration, miniaturisation and processing power have brought about a noticeable increase in computing and electronic devices that now surround us in our daily lives. We use computers and processors every day even without noticing it, starting from the moment we turn on the lights in the morning, use the microwave, make a phone call or get into our car. The ever-increasing number of devices also inevitably brings new kinds of functionality, user interfaces, functions and increased complexity, which is something we have to cope with. Often, however, there are situations where we do not understand or remember how certain actions (e.g. installing new devices, changing configuration, setting up home networks) are performed. This can cause frustration, technophobia, or reluctance to use the advanced functions of electronic devices. In a home environment filled with automation, appliances, home entertainment, PDAs, laptops, mobile phones and computers, there is already now a plethora of devices we must learn to use and maintain in our daily routines. Despite convergence and the integration of functions, it is likely that the number and complexity of such devices will continue to increase.

For the future home a few years from now this increase in electronic devices raises certain issues: how will these devices work together, how can they all be interconnected to enable more intuitive control of the future home and what possibilities would such a home offer its occupants. The smart home is a concept that promises improved ways to control functions in the home, flexible networks that can connect to any device, adaptive control facilities and peace of mind for its occupants. This is the goal, but how can it be achieved using present technology? The key elements to achieve this are intuitive, flexible user interfaces and device compatibility.

Three different smart home research environments were constructed to investigate these issues: the Living Room, the Smart Home and the eHome. This thesis discusses the design, implementation, development and findings of these projects with brief mention of related smart home projects and technologies. The research was conducted between 1999 and 2009 at the Department of Electronics. The focus is thus on hardware design and implementation, communications, user interface prototypes and home networks; each of these topics is presented in a separate respective chapter. In order to obtain results from authentic life situations, these systems have all been built and implemented in real environments and later tested and evaluated by various test persons. The findings of the study are presented and discussed, with some conclusions on the future of the smart home.

Preface

This thesis presents research that has been carried out from 1999 to 2009 in the Personal Electronics Group at the Department of Electronics at Tampere University of Technology, Tampere, Finland. The work has been funded primarily by the department, with certain projects also being funded privately or by the Academy of Finland. Partial funding also came from the Graduate School in User-Centred Information Technology (UCIT).

The impetus for smart home research at the department came from Prof. Jukka Vanhala, whom I would also like to thank for the inspiring research themes and his guidance over the years. A debt of gratitude is also due to present and past members of the Personal Electronics Research Group (PEG) who encouraged and assisted me in this research. Our friendship also extends outside the office environment. Smart home research at TUT has been a collaborative effort and none of it would have been possible without the originality and enthusiasm of the researchers.

I am also grateful to the reviewers of my thesis, Prof. Albrecht Schmidt and Prof. Petri Pulli for their valuable comments on the manuscript, Dr. Harri Raittinen and Dr. Jaana Hännikäinen for their assistance and Alan Thompson for proofreading the manuscript. Thanks also go to everyone who sent me pictures for this publication, to the Drunken Old Farts Internet community and Christopher Franke for his inspiring music.

Finally, I would like to thank my family and relatives for their enduring support, especially my wife, Pilawan, for being that special one for me.

Tampere, December 12, 2009

Lasse Kaila

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List of Abbreviations

AC	Alternating Current
ADC (A/D)	Analogue to Digital Converter
AI	Artificial Intelligence
AmI	Ambient Intelligence
API	Application Programming Interface
ASCII	American Standard Code for Information Interchange
BAN	Body Area Network
bps	Bits per second
CAN	Controller Area Network
CPU	Central Processing Unit
dBm	Power ratio in decibels (dB) referenced to one milliwatt (mW)
DC	Direct Current
DLNA	Digital Living Network Alliance
DSL	Digital Subscriber Line
DVD	Digital Versatile Disc
ECG	Electrocardiography
EEPROM	Electronically Erasable Programmable Read-Only Memory
EMC	Electromagnetic Compatibility
EPIS	Efficient Protocol for Intelligent Spaces
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HCI	Human-Computer Interaction
HDTV	High-Definition TV
HTML	HyperText Markup Language
HTPC	Home Theatre PC
HomePNA	Home Phoneline Networking Alliance
HVAC	Heating, Ventilating and Air-Conditioning
I/O	Input/Output
I2C (I^2C)	Inter-IC bus
IC	Integrated Circuit
ICT	Information and Communication Technologies
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
IR	Infrared
IrDA	Infrared Data Association
ISM	Industrial, Scientific and Medical
ISTAG	Information Society Technologies Advisory Group
IT	Information Technology
IP	Internet Protocol
ISO	International Organization for Standardization
LAN	Local Area Network

LIPS	Learning and Interactions in Proactive Spaces
LON	Local Operating Network
MCU	Microcontroller Unit
MEMS	Micro-Electro-Mechanical Systems
MOSFET	Metal–Oxide–Semiconductor Field-Effect Transistor
NFC	Near Field Communication
OS	Operating System
OSI	Open Systems Interconnection
PAN	Personal Area Network
PC	Personal Computer
PCB	Printed Circuit Board
PDA	Personal Digital Assistant
PIR	Passive Infraeed
PLC	Powerline Communication
PnP	Plug and Play
QoS	Quality of Service
RAM	Random Access Memory
RF	Radio Frequency
RFID	Radio Frequency Identification
RSSI	Received Signal Strength Indication
RTOS	Real-Time Operating System
RX	Receive
SD	Service Discovery
SMS	Short Message Service
SPI	Serial Peripheral Interface
TCP	Transmission Control Protocol
TUT	Tampere University of Technology
TX	Transmit
UART	Universal Asynchronous Receiver Transmitter
UDP	User Datagram Protocol
UI	User Interface
UPnP	Universal Plug and Play
USB	Universal Serial Bus
UWB	Ultra Wideband
VPN	Virtual Private Networking
VR	Virtual Reality
VTT	Valtion Teknillinen Tutkimuskeskus (Tech. Research Centre of Finland)
WAN	Wide Area Network
WLAN	Wireless LAN
xDSL	(x=(A)symmetric, (S)ymmetric) Digital Subscriber Line
XML	eXtensible Markup Language

1. Introduction

1.1 Smart Homes

Ubiquitous Computing, Pervasive computing, Ambient Intelligence, Smart Homes, Everyware, etc. predict the coming of a new age of modern living. According to these predictions our future homes will be filled with electronic devices, all interconnected and around us, sharing information and making our lives easier. In order to better understand the concept of the smart home we may take a brief look at the past to see how technology has impacted our daily lives. The emergence of electric home appliances in the beginning of the 19^{th} century changed the way we perform our daily chores at home and revolutionary innovations have made our lives easier and more comfortable. Once a certain level of home appliance adoption had been reached the time came for the next wave in home electronics, which included various kinds of home entertainment. The focus shifted from work to leisure and the technology was adopted rather quickly, bringing us televisions, radios and tape recorders. In the late 1980s the emergence of the personal computer saw another wave of technology and it also quickly found its way into our homes. Today we are accustomed to using such devices in our daily lives without giving it a second thought. Technological development clearly does not end here, and the increasing number of devices, user interfaces and functions present new challenges in terms of compatibility, management and usage.

Personal computers, wireless networks, home gateways, Internet connections and device convergence have all opened up new possibilities and we can now perform computing in various locations and forms. A smart home contains many kinds of devices, sensors and user interfaces and in order for these to communicate with each other, share information and processing power they need to be connected to each other. Thus, seamless networking and device interconnectivity is a fundamental requirement for a smart home, as Mark Weiser [Weiser91] observed in his views on Ubiquitous Computing. Unfortunately this requirement for compliancy and compatibility still presents a difficult obstacle as there are so many competing standards and technologies available today and some devices are completely without a communication interface. From a technical point of view a smart home does not require state-of-the-art technology or futuristic gadgets; the technology for creating smart homes has been available since the 1970s and technically there are no obstacles to prevent smart homes being constructed already today [Tiresias08]. However, there are several factors that have prevented smart homes from being widely available. Though several commercial and non-commercial showcases, technology demonstrators and prototypes have been built [Nyseth04, HP01] the smart home remains a distant dream.

In order to find out what kinds of opportunities, barriers and future prospects there could be for smart homes, a research group (of which the author was a member) was formed at the Department of Electronics. Research started in 1999 by converting former laboratory space into a smart home laboratory. The author’s first project was to implement smart devices for this laboratory, something that later grew into participation in the implementation of three smart spaces.

1.2 Structure of the Thesis

This thesis discusses the idea of smart home technology in general, how the idea of a smart home was conceived and how it has been interpreted around the world. This chapter sets out the scope of the thesis and defines the research question. Chapter 2 starts by introducing various interpretations of the subject, explains the differences between these and presents the ideas that have been used in research at Tampere University of Technology (TUT). Chapter 3 discusses various aspects of creating smart homes, the kinds of obstacles one might encounter on the way, what kinds of benefits smart homes could offer users as well as a brief history of the development of domestic technology. In Chapter 4 there is an overview of current state-of-the-art technology and related research projects are presented. Chapter 5 presents smart home research projects from a nine-year period at Tampere University of Technology. Chapters 6 and 7 present different hardware and software solutions, such as networks, sensors, middleware, etc. that are commonly used in smart home applications. Chapter 8 presents different types of user interfaces and interaction methods with smart homes while Chapter 9 summarises the findings from smart home projects at TUT. This chapter also considers the various problems and challenges encountered during the research and summarises the findings and lessons learned during this nine-year period. In Chapter 10 there is further discussion along with an analysis of the current and possible future state of smart home technology and finally some concluding remarks.

1.3 Scope of the Thesis

This thesis concentrates mainly on the technical aspects of smart homes as this is as it is also the standpoint from which research has been conducted. Since smart home research in general spans multiple disciplines this focus will naturally limit the scope of the study to hardware, software and communication. Practical findings, results from user tests and other issues related to everyday use are also presented. Usability issues (aside from practical issues), psychological perspectives and software engineering (e.g. PC software, signal processing algorithms) are thus excluded. Smart environments or smart spaces are a more general name for this kind of research, but in the context of this thesis the environment in question is a home as a physical space. Mobile computing (that takes place outside the home and is not related to controlling functions in the home), wearable computing (e.g. smart clothing) and related technologies also lie beyond the scope of this thesis. Networks exclude body area networks (BANs) and wireless personal area networks (WPANs) provided they are not used for controlling or interfacing with the home networks and devices.

1.4 Contribution

During the years that smart home research has been conducted at the Department of Electronics the research contribution has been made by a large group of research assistants and scientists in the Personal Electronics Group. During the first years the group consisted of the author and two colleagues, while in 2001 the group had almost two dozen people working on projects related to smart environments. As a result there have been numerous people

working on all the various designs that TUT smart home projects involved, and in some cases it is difficult to identify individual developers and responsible persons. The author has been designing smart spaces and devices since 1999, from the Living Room test environment and the first sensors and actuators for it until later moving on to the Smart Home laboratory and the eHome (all of which are presented in Chapter 5). During the course of these projects various contributions by the author have been published in **[**Kaila01, Kaila05_1, Kaila05_2, Kaila07, Kaila08, Kaila09**].**

The first implementation for the Living Room test environment was a flowerpot sensor module, its infrared communication protocol and parameters. This work (any many subsequent projects) was done in collaboration with colleagues Petri Keski-Opas and Jussi Mikkonen. As this work progressed, more devices were created and the Living Room space was built, again with the help of the same people plus a few newly recruited research assistants. Building the Living Room involved much of practical work; designing the layout, electrics, installation, furnishing and supervision of contractors. More devices, such as lighting control, floor sensors, controllable door etc. were built after the laboratory was completed while Jussi Mikkonen concentrated on the wireless network and protocols. Markus Ritala designed the first graphical user interface and control software which was embedded into a tabletop computer. A few years later in 2002 the department moved into a new building making it possible to design a new larger test environment. Together with Pasi Myllymäki new designs were made, now with modularity and expandability in mind. Markus Ritala and Antti-Matti Vainio designed a new modular Home Controller software package, allowing the new laboratory to be more flexible and easy to develop for future needs. Building the new testing space also required much work, with old designs being removed from the Living Room, re-installed into the Smart Home and new features being implemented. New sensors for temperature and humidity were made, as well as controlling electronics for window blinds, lights and curtains. Controlling systems for 240 V mains electricity were supplied by a third party as well as furniture and interior design. Later in 2002, work expanded into another test apartment (the eHome) in downtown Tampere, requiring further installations and preparation for user tests. During this project the author was also in charge of the TUT research team. As the three-year project progressed there were occasions when a visit to the apartment was necessary in order to carry out repairs or make modifications to the system. Since the conclusion of the eHome project the author has mainly been responsible for the upkeep and development of the Smart Home laboratory at TUT, as well as participating in new research projects, such as UUTE and LIPS (presented in Chapter 5). Another TUT research project, the Morphome, is also presented in this thesis because it is closely related to other projects. However, the author has not been involved in this particular project.

The aim of this thesis is to contribute to smart home research by presenting the following items :

- Practical experiences from three smart home projects
- Review of related work and research
- Findings and thoughts on real-world implementation of smart home hardware, software and user interfaces
- Advantages that smart homes can offer, challenges that still remain
- Guidelines for creating a home network and control system

1.5 Motivation

As mentioned above, modern life involves the use of a wide range of electronic devices and appliances. One major problem is that each device has its own operational logic and user interface and the way one device works might be very different from another similar unit from another manufacturer. With the ever increasing number of devices being introduced into our daily lives, it is hardly surprising that users are overwhelmed by the need to remember how to operate them all. Furthermore, the number of features and functions that a single device is able to offer is constantly increasing as well. All this might lead to confusion, frustration and cause situations where users only employ the basic features of a device and ignore the rest [Green04]. For example, a user of a modern mobile phone might be unmotivated to read instruction manuals, and use only basic functions such as making phone calls, sending SMS and adding phonebook entries. Other functions might be hidden under a myriad of menus and submenus, require initialisation or some form of setting up. The user might thus be unaware of the other functions the phone offers, such as calendar, calculator, alarm, unit converter etc. A similar problem can occur in a home environment if a power outage resets the alarm clock or the clock on the microwave oven; most users have to resort to the user's manual in order to set the time. When a new TV set is purchased considerable time must be spent on connecting all the devices to it, setting up the system and tuning the TV channels. Such problems can be frustrating and overwhelming, making the prospect of a future home filled with even more electronics even more daunting [MS07].

A smart home should be able to overcome this problem: a smart home containing sensors, actuators and user interfaces must be capable of interacting smoothly with both devices and users. However, connecting all possible home devices and appliances is not enough; practical issues, such as interoperability and compatibility must also be taken into consideration. When using modern electronic gadgets that process information there is often a need to transfer this information to another device or computer. Problems arise if the devices or the information is not compatible or if the one device lacks functionality that the other one has. To a certain extent traditional 'unintelligent' electronic devices can be compatible with other devices, and it has been easy to take this into account in the design process. Television sets, for example, can accept the video signal from almost any brand or type of DVD player (data/signal compatibility) provided the physical connector fits, and an energy-saving light bulb can be used instead of a traditional one (physical/electrical compatibility). A smart device can also be relatively easy to design because its construction and

functions can be designed to suit a specific application. However, compatibility problems arise when these devices are used together with other smart objects. Communication between devices becomes impossible because this facility has not been taken into consideration when the devices were designed. The global market does not wait for common interconnectivity standards to emerge; instead manufacturers continue to use their own communication standards, making devices that are introduced to the market incompatible with each other from the outset. This is a fact that cannot be overlooked and one that must be considered in the design of smart environments. From the consumer's point of view the situation is understandably difficult and frustrating. This is all the more alarming when it is remembered that the idea behind smart spaces is to reduce stress and improve the usability and living experience of the users [Weiser96].

Smart, networked homes can also offer other advantages: when devices are connected to each other, either directly or through a server, they are able to access and use information that would otherwise be unavailable. They could share time information, location data, processing power, etc. with each other through the network. When sensor data from all around the home is collected and combined the system (and the user) can gain a much clearer picture of the situation in the home. For example, a temperature sensor in the living room could only measure the temperature in that particular location, and if the temperature starts to drop a home automation system would simply turn the heating up. A networked smart home, on the other hand, could utilise other sensors in the room and register that the window has been opened because of bad air quality inside the room. On subsequent occasions the system will already know the reasons and proactively take the necessary action. Thus, information which in isolation may seem insignificant can actually be valuable when considered and compared with other measurements and information from the home.

Another often overlooked aspect of smart homes is the addition of intuitive and logical user interfaces that would lessen the burden of managing the home. For example, a graphical home user interface would offer great flexibility and adaptability when thinking about controlling A/V equipment, access control, monitoring energy consumption and managing security. The user interface (UI) of every device could be made to look similar, and only relevant functions could be enabled depending on the current user and context. The DVD player, VCR, set-top box would have similar controls and traditional infrared remotes would no longer be required. Likewise, instead of simply turning off a light somewhere in the home, the switches could be programmed to perform any function in the home. For example one button could be a master “all off” - switch, which would turn off all lights in the home when the users are going out. Certain features could be disabled to suit the users that access the system (for example children could not turn on the kitchen stove) and remote access could enable users to monitor the home from a remote location with a mobile phone. UIs need not only be physical or graphical, there are obviously other ways of interacting with the home, for example, by using gestures, speech or other natural forms of communication.

When considering the smart home as a physical space there was one further reason that inspired us to start experimenting with smart homes. Despite the number of smart home research projects in the world, very few had actually implemented a complete apartment, let alone in 1999. In many cases there had only been laboratory tests, simulations and net-

worked media homes but cases where a complete, functional infrastructure along with UIs and controlling software was implemented were very rare. Since the Personal Electronics Group has always emphasised prototyping and practicality, this seemed a logical course of research. The initial goals of the research were the creation of a relaxing smart space with interconnected devices and different kinds of user interfaces. Later on, plans were made to conduct long term real-life studies with actual inhabitants in a normal everyday scenario.

TUT smart home research used the following research methods :

- Design and implementation of smart home hardware, software and user interfaces
- Installation of functional prototypes into the test environment
- Implementation of test environments with a control system in order to obtain experiences from using various user interfaces, controlling the home and interfacing with devices
- Conducting experience prototyping [Buchenau00], user and technical tests in test environments
- User tests conducted by a professional researcher (in the eHome)
- Periodic iteration and improvement of the test environments

1.6 Research Question

As consumption researcher Mika Pantzar has observed, the technical development of domestic technology can be divided into three phases [Panzar00]. The first of these, roughly from the beginning of the 20^{th} century until the 2^{nd} World War basically focused on technical development, new kinds of household machines and automation. In the 1970s the focus shifted towards computers and the emerging information technology. Currently, in the 21^{st} century, the focus is on the enrichment of daily life, new experiences and more user-friendly development.

This development has made us increasingly dependent on technology, while at the same time, our lives and routines have become accustomed and shaped by it. This raises two questions:

1) How should new technology be designed so that users can benefit from it? If users have to cope with an increasing number of electronic devices it can cause problems, stress and frustration towards new technology. As our homes are already filled with electronic gadgets the way devices are used, managed and installed becomes a very important issue.

2) How can complexity be reduced without any loss of functionality in the process? If a smart home consists of multiple networks, devices and user interfaces how is it possible to create a functional, usable system without sacrificing performance, functions or resources?

When new technology is designed it is easy to focus on the technological innovations, such as new processors, faster networks, new software features, etc. Other issues, like usability, durability and integrability are considered of secondary importance and are easily overlooked. When thinking about smart homes this is clearly a disadvantage, making technol-

ogy seem like an obstacle rather than an enabling factor. One major element in this problem is compatibility: if devices, appliances and applications can be made to work together this would certainly increase the benefits and make technology more useful, easier to use and install. In actual fact, however, there are many levels of compatibility that have to be taken into consideration:

- **Physical** : Defines how objects fit together, for example, connectors, physical dimensions, how they fit into the user's hand etc.
- **Electrical** : Operating voltage, frequency requirements, batteries and other power supplies, interference tolerance, electromagnetic compatibility (EMC)
- **Communication** : Protocols, compatibility of different kinds of signals, connectors, and cables
- **Information content** : Context information, semantics, ontologies
- **Social** : Services, social acceptance, personal security, privacy issues
- **Psychological** : Stress, burden, learnability, ambience
- **Financial** : Price, requirements, operating costs

In TUT the emphasis of smart home projects has been on the first three items, and later expanded to encompass other items as well. Since the research has been academic and mostly funded by the department, financial considerations (production costs, marketing standpoint, etc.) have not been considered in greater depth.

2. Definitions

This chapter presents various views on smart homes, the kinds of interpretations that exist and the terminology closely related to the topic. The definitions are compared to the guidelines used in smart home research at TUT. In addition a comparison is made between smart homes and home automation.

There seems to be little universal agreement as to what is meant by the concept of a smart home. This is immediately evident from the many different names used to refer to the subject itself: smart spaces, ubiquitous computing, pervasive computing and ambient intelligence to name a few. There are several variables and nuances that differentiate between the different definitions. A distinction can also be made between information processing (e.g. ubiquitous computing) and control of the environment (e.g. proactive computing). The space that these definitions refer to can be any building or room provided it contains the necessary infrastructure (e.g. intelligent environments). Differences between definitions start to emerge when considering what the smart environment contains, how it works and the kinds of functions it offers and the kinds of interactions being contemplated. For example, the term smart home can be used to refer to a traditional home where technology works unnoticed in the background or it might refer to a high-tech home with broadband networks, video-on-demand and big screens on the walls.

Frances Aldrich [Aldrich03] presents a classification for smart homes according to different levels of communication; whether the home is capable of learning and if it is aware of its occupants and installed devices. The classification contains five groups:

- Homes that contain intelligent objects (standalone appliances that contain some kind of intelligence)
- Homes with intelligent communicating objects (intelligent appliances and objects are able to communicate with each other and exchange information)
- Connected homes (homes with both internal and external networks, making them and their services accessible from inside and outside)
- Learning homes (homes that record and adapt to behavioural patterns of their users, control the devices accordingly and predict the user’s future actions)
- Attentive homes (homes that constantly monitor their users and use this information for anticipating their needs)

The Smart Homes Association, on the other hand, defines smart home technology as “the integration of technology and services through home networking for better quality of living” [Tiresias08].

2.1 Ubiquitous Computing

Over a decade ago views and theories began to take shape of computers and computing capacity that is available everywhere, anytime and via any device and also about how com-

puters would disappear into the background [Weiser91]. Mark Weiser's theory was that evolution would go from one computer, many users (mainframe era) into one computer, one user (personal computer era) and in the future to one user, many computers (ubiquitous computing). According to Weiser computers were to be available everywhere, but would be invisible to the users until actually needed. They would share information, processing power and user interfaces, thus enabling computing to take place anywhere anytime while remaining unobtrusive. Virtual Reality (VR), where people are put inside a virtual computer-generated environment is in some respect the opposite of Ubiquitous Computing, where computers are forced to exist in a real environment. Alan Dearle has taken the theory of Ubiquitous Computing even further to include the whole world with the concept of Global Smart Spaces [Dearle03]. Global Smart Spaces would support location-aware interaction between people, devices and places on a global scale.

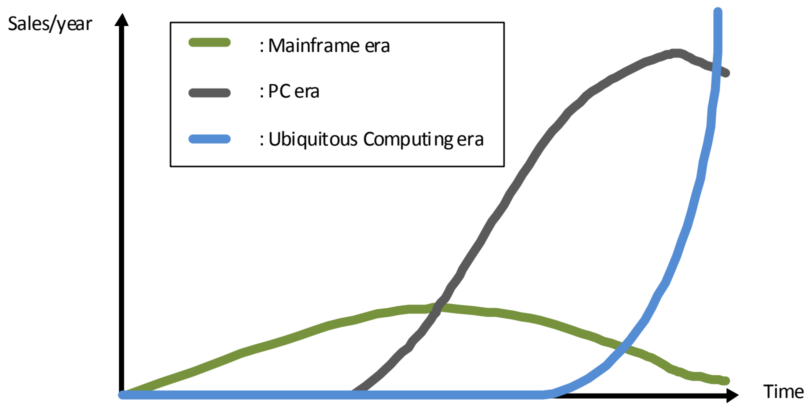

Figure 2.1 Graph of the evolution of computing, showing the three separate eras [Weiser91]

A more recent study [Tolmie02] however suggests that invisibility might be purely cognitive, and that the term relates more to how we perceive and use computers. Once users have grown used to having computers and gadgets around them, they become accustomed to them and no longer think of them as separate entities but rather as user interfaces and access points for information. Thus far it seems that ubiquitous computing has only advanced to the point of one user and many computers. Current household items indeed contain processing power, memory and some form of user interface, and in a modern home the number of electronic devices is considerable. However the idea of networked, resource-sharing computers has still not materialised, with applications still isolated and unaware of the rest of the system. Some gadgets, such as the Nabaztag [Nabaztag06] (a rabbit with WLAN that checks e-mails, weather reports and reads news) and Ambient Orb [AmbOrb07] (a similar device, that changes its colours to reflect changes in weather, new e-mails etc.) have network connections but they do not interface with any home electronics. Moreover, the task of configuring and connecting these things already requires extensive knowledge about wireless LANs and related settings, not to mention the effort of actually setting up a secure wireless home network.

2.2 Ambient Intelligence

The term Ambient Intelligence (AmI) was introduced by electronics giant Philips in the late 1990s [Philips98]. The AmI concept was built around telecommunications, home electronics and computing, which naturally relates to the company's product selection. The idea of AmI is to create electronic environments that are sensitive to the presence of people, anticipate and react to their needs. In order to make this possible, unobtrusive hardware, seamless communication and computing and human-centric user interfaces are needed. Philips has complete facilities for testing and demonstrating AmI concepts in the form of the Home Lab, which opened in Eindhoven in 2002. The Home Lab contains large displays, speech recognition interfaces and the latest home entertainment technology. It also contains cameras and equipment for usability studies for experimenting with new technology.

According to [Pieper98] Ambient Intelligence is:

- Embedded (the environment contains invisible networked devices)
- Personalised (the system knows your identity, and it can be personalised)
- Adaptive (the system can change its behaviour according to your actions)
- Anticipatory (the system anticipates the user's needs)

Ambient Intelligence is not limited only to home environments, it is applicable to cars and wearable personal electronics as well.

Another definition written by the EU Information Society Technologies Advisory Group (ISTAG) AmI is based on three key technologies, [Ahola01, ISTAG01] ubiquitous computing, ubiquitous communication and intelligent user interfaces. Ubiquitous computing, as previously mentioned, concerns the way processing power is being integrated into everyday objects such as clothing, furniture and structures. Ubiquitous communication is the media that enables communication between objects, using wireless ad-hoc networks. Intelligent UIs present the interface for users through which they can control and interact with the environment. The emphasis of AmI is on user-friendliness, enhanced service support, user-empowerment and support for interactions between humans. In other words, people will be surrounded by intuitive, intelligent interfaces, in every object and environment. Implementing AmI is not straightforward, adding computational power and communication links to an object does not make it intelligent. A learning, adaptive intelligence is also required to make everything work as a whole.

The IST group report [ISTAG03] also lists the requirements for ambient intelligence and divides these into two categories: components for ambience and components for intelligence. Components for ambience include new smart materials, such as electronic paper, sensor film, materials that emit light and that can store data, etc. New Micro-Electro-Mechanical Systems (MEMS) can be used to construct tiny actuators, and other kinds of new sensors can also be used to bridge the gap between human and machine senses. On the hardware side, self-configuration, on-the-fly programming and self-repair allows for more reliable systems and rapid development whereas ubiquitous networks make it easier to access any device in the space, using either active or passive communication. For this pur-

pose the software in the devices also has to be adaptive and self-managing in order to manage and adapt to changes in the environment. Components for intelligence include components for handling and managing media for analysis and presentation of captured content and methods of natural interaction using multimodal technologies. Computational intelligence adapts to human behaviour and together with contextual awareness it can present relevant information for its users, depending on the current conditions.

The same report emphasises that AmI is a research field that incorporates expertise from technological, societal and economic fields. According to the report it is also important to stress that in AmI the intelligence is provided through interaction and participation, addressing the real needs and desires of the user. This is different from the traditional view of artificial intelligence as an inferior, abstract entity that people cannot really communicate with. When the intelligence resides in the environment, networked devices and content it can provoke negative reactions at first because it is very unfamiliar, invisible and unobtrusive. The goal of the group is thus to promote the benefits and possibilities of AmI technology.

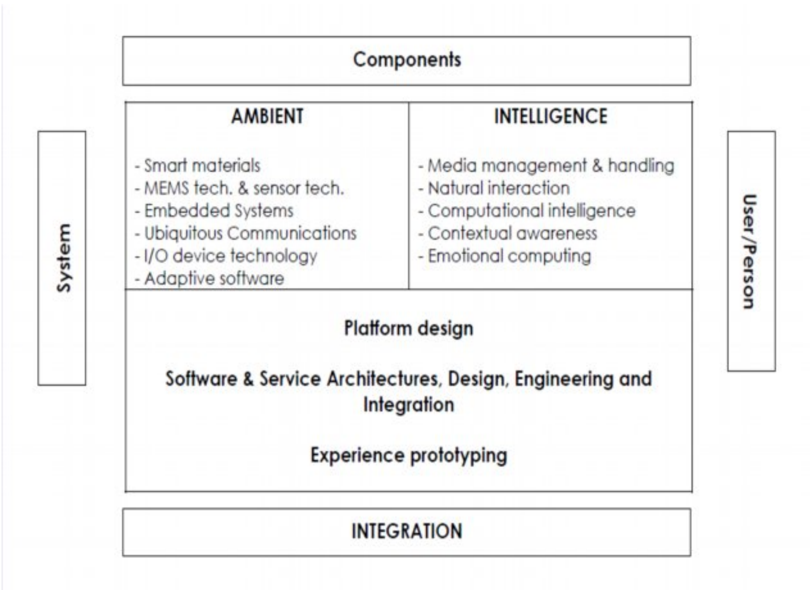

Figure 2.2 Building blocks and technology requirements for AmI [ISTAG03].

2.3 Pervasive Computing

Pervasive Computing is generally considered to be a synonym for Ubiquitous Computing, though the term was introduced by IBM in 1998 [IBM98]. The term “Pervasive” itself refers to something that is everywhere all around us, in this case computing. As information technology has become cheaper and faster every year the amount of processing that devices are able to perform has made it possible to create smart devices that can make our lives

easier and more productive. Information technology has thus moved from computers into everyday devices, including home entertainment, personal digital devices and mobile phones. Pervasive Computing makes it possible for users to conveniently access information using new networks and communication technologies, bringing new possibilities and improving the quality of our lives. Relevant information is available whenever and wherever the user needs it. The Pervasive Computing concept also includes third party services, support and other businesses such as content providers. IBM has a Pervasive Computing Laboratory in Austin, Texas for demonstrating new pervasive technologies, artificial intelligence, voice recognition and wireless computing.

According to Uwe Hansmann [Hansmann03], Pervasive Computing can be divided into four fundamental paradigms:

* **Decentralisation**: The shift from centralised mainframe computers to distributed computing, PDAs, mobile computing devices and PCs. Information is accessible everywhere from any device, data and processing can be shared throughout the network.

* **Diversification**: Numerous alternatives are available for each application, and it is possible to tailor a suitable software/hardware platform using available components. Each device has its own purpose, and even if some properties might overlap between devices there will still be different user scenarios for all of them. Presenting information and managing a myriad of different devices poses major challenges for UI design and data management.

* **Connectivity**: A device can use multiple networks to connect to the Internet or other devices, and it can seamlessly change over to another network if the previous network becomes unavailable or a more suitable network becomes available. Gateways and converter modules can be used to connect an incompatible device to another network type, but ultimately it is applications and their interoperability that determine how compatible systems are with each other.

* **Simplicity**: Increased functionality, new networks and applications also tend to make devices more complicated. Pervasive computing should be the opposite, requiring minimal effort and thus avoiding becoming a system with hierarchical menus and multiple menus. Great care must therefore be taken when designing UIs and functions for pervasive technology.

From the previous design goals it is clear that there is a need to have an embedded network infrastructure and compatible devices in order to create a smart home network. Pervasive devices should be optimised for specialised tasks and not for general use, thus they can be designed to be easier to use and maintain.

2.4 Our Definition of a Smart Space

The Personal Electronics research group regards a smart space (in our case, the environment is always a home) as a physical space consisting of networked devices and sensors that are able to monitor each other and the conditions inside the space. The system is able

to detect the presence of people and react accordingly by making autonomous decisions and affecting the space in a physical way. This definition is similar to the definition of T. Kanter [Kanter00]. However, merely adding and connecting sensors and actuators in a space is not enough. A smart space should also be able to perform complex reasoning and adapt itself to the users' routines and habits. Thus, even if a space consists of several very complex and advanced independent systems, it cannot be considered a smart space if these systems are not interconnected in any way. As a result, home automation, HVAC control, pre-programmed systems and other standalone applications lie outside our definition, as they do not offer all the functions expected of a smart system.

A smart home need not be physically different from a traditional ("non-smart") home; differences will become clear in other ways. To give an example of what a smart space could be like, consider a space with a locationing system, environmental sensors and networked home appliances. Using the sensors and location information it is able to gather information about the space and the actions of the users. If the control system determines that an action should be taken it can perform the necessary actions according to learned patterns or weighted predictions. When a person enters a smart home the space will react in some way to his/her actions. For example, if the user is wearing an ID tag the computer will recognise him/her, greets the user and a personal profile will be loaded along with appropriate lighting levels and temperatures for the room. Another scenario is when a person wakes up in the morning. Instead of a buzzing alarm clock, he/she can wake up when the window blinds slowly open, letting more light into the room. If it is dark outside, the computer can use the bedroom lights instead to turn up the brightness in the room. This offers a more pleasant and natural wake-up. After a while, when the user has woken up the blinds will briefly close again, allowing the user to get dressed or take a shower.

A smart home should be able to serve its users during all stages of their lives, adapting and changing itself according to people's requirements and needs. Moreover, in order to keep the smart environment a relaxing and pleasant environment there have to be intuitive ways of controlling devices, systems and appliances in the home. This can be achieved by offering additional ways of communication, interaction and control whilst also maintaining traditional ways of using devices in the home. This also means that manual control should always be an option, and that users can choose the most suitable way of controlling the environment. For example, if users want to change lighting levels in the living room, they can either use wall switches, voice commands, a mobile phone UI or control them from a computer screen. Offering many control UIs makes devices and applications ubiquitous as there can be multiple ways and locations from where a certain device can be controlled.

This definition does not specify what kinds of networks should be used or what kind of central intelligence there should be, nor where it should be located.

An early description of the fundamentals of TUT smart home research, is still valid today [TUT00]:

"*When talking about the future home people usually envision complex home automation, broadband networks, talking machines, robots, etc. People rarely start to think about practical issues and if the technology can really be useful to us in everyday life. In the TUT*

Smart Home research project these things are viewed from the users' point of view. Home automation and things that happen behind the user's back can start to become annoying in the long run, they cause stress and make the user passive. Our principle is instead to activate the user, i.e. make the user do everyday chores and take care of the home. For example, instead of an automatic plant monitor that would water the plant regularly the user will be reminded to do so if the plant requires it. If nobody is at home the system can either set a reminder for the user or switch to an automatic mode.

Because the system is programmable some events can be automated. For example lights can be lit when the user walks into the kitchen. This can also be combined with user identification, and a personalised profile can be created for each user. Also one further requirement is to avoid adding user interfaces (displays, buttons, blinking lights) to devices themselves, but instead keep them as they have been before. This is according to the Natural User Interface principles. Controlling and using devices would instead be done centrally, for example by using a web-based user interface on a PC. For example a coffeemaker would not need any buttons or additional user interface components, the electronics will be hidden inside the device and it could be controlled wirelessly from a control UI.

In order to implement a smart home devices have to be able to communicate with each other wirelessly. This has been implemented with infrared and radio links. Measurements, control and communication are done with embedded microcontrollers in the devices. Common features for these devices are small size, low power consumption, low price and wireless connectivity. A test laboratory has been built at the institute, where different kinds of smart devices have been installed for usability and practical testing."

The TUT definition combines parts from previous definitions, as there are networked devices and sensors, contextual reasoning and improved usability and security. There are, however, notable differences. For example processing power is not shared among devices as such, as most processing can be done either centrally or independently in devices. Users' actions are monitored but interactions between users or with computers are not analysed or monitored in a specific way in order to extract their contents.

2.5 Proactive Computing

Proactive Computing monitors the context of the users and, depending on the captured context (context recognition is described in more detail in chapter 2.10) and learned patterns, the system can take the appropriate action [Mäyrä05]. The idea behind proactivity is that the system can anticipate user behaviour and prepare for the next actions in advance without the user noticing it. Thus the lag will be minimal and use of available resources optimised.

One goal of proactive computing is to take the human out of the control loop [Tennenhouse00]. Interactive computer systems are restricted so they operate at the same performance level as humans but when this limitation is removed the computer system can

freely be let to “run ahead” of the user, anticipating and predicting possible near-term actions and enabling faster response times. New challenges arise when UIs for proactive faster-than-human systems are developed, and according to the author computer science should be directed towards the physical world and everyday reality.

2.6 Mediated Spaces

A Mediated Space is a kind of a smart space that understands and participates in multiperson interaction [Mark99]. In other words it differs from other points of view by concentrating not only on human-computer interaction but also on the interaction between people. The Mediated Space is constantly gathering information about the users and from the outside world, and it is monitoring the users and analyses their contexts, for example through speech and gestures. For example, a mediated office room would assist a group of workers in carrying out their project work by providing relevant information and proactively providing data that could be useful during the workflow. A Mediated Space requires both behind-the-scenes technology that coordinates activities and exchanges data between devices, and at-the-interface technology that relates to how people perceive the space and how multiperson interaction is managed.

As computing in the future changes from a one user-one computer scenario (where users are implicitly sitting in front of the computer and using it) to a pervasive computing space with embedded computers everywhere and multiple users in the space, our perception of computers and the way we use them will completely change. The physical location of the computer becomes irrelevant but the identity and location of the user again becomes significant. A Mediated Space also requires sensors for recording and understanding speech, gestures, user identification and data analysis. The last requirement is fundamental, and it practically means that a Mediated Space has to understand what computations the computers are performing in order to understand what people in the space are saying, doing or pointing at. This again implies that the space must also be aware of what devices the space currently contains, their capabilities, properties and also their orientation.

All these requirements make it extremely difficult to implement a Mediated Space using today’s technology. Making computers understand speech and gestures, locating and identifying devices and people who can freely move around in a space and understanding all interactions between these is something that current technology is not able to do, at least unobtrusively and in real-time.

2.7 Intelligent Environments

Intelligent Environments is a more general term, stemming from interactive environments by bringing the computer more to the background and using more natural forms of interaction between users and computers. Blair MacIntyre proposes that interaction should not be through menus, windows and other mouse-driven interfaces but instead through gestures, speech, context and affect [MacIntyre98]. People should be unaware they are interacting with a computer. Another definition describes Intelligent Environments as “spaces

in which computation is seamlessly used to enhance ordinary activity“ [Coen98]. As the name implies, Intelligent Environments encompass all kinds of spaces, such as offices, meeting rooms, hospitals etc. Intelligent Environments are both embedded and multimodal, which means that they use cameras, microphones and other sensors for sensing real-world phenomena and computer software to interpret and understand them. This approach does not require the same kind of hardware and sensors as Ubiquitous Computing, instead the focus is on unencumbered interaction with non-computational objects.

Thus far seven different definitions have been presented, and it would seem that they all look at things from a slightly different perspective, each having their own presumptions, goals and enabling technologies. Ubiquitous Computing and Pervasive Computing both rely heavily on ad-hoc networking, resource sharing and new kinds of human-computer interaction. Ambient Intelligence is also using Ubiquitous Computing as enabling technology, but emphasis is on user recognition and user-centricity. That is, AmI creates the media for person-to-person and person-to-computer interactions. Proactive Computing, on the other hand, aims to relieve users of lower-level functions and lets the computing system handle context recognition and anticipation of the user’s actions. This approach requires a significant amount of signal processing and a complex software architecture, something that is even more important in the case of Mediated Spaces. Mediated Spaces require a large network of sensors as the system has to be able to understand the interactions that are taking place in the space. Gathering sensor data is rather straightforward, but analysing and understanding its meaning is quite a challenge for software developers. Intelligent Environments leave the ubiquitous hardware and software in the background and focuses on usability, natural interactions and straightforward control of the environment. The TUT definition relies both on ubiquitous hardware and software, but it is the seamless cooperation of hardware and software that enables a flexible, adaptive smart home system.

Table 2.1 summarises the main themes and perspectives of the different definitions.

Table 2.1 Main themes and differences between the definitions

	Main themes	From the computer's perspective	From the user's perspective
Ubiquitous Computing	Processing power integrated into everyday objects	Computers are everywhere around us	One user, many computers
Ambient Intelligence	An environment that reacts to the presence of the user	Seamless computing and communications	Support for human-human interactions
Pervasive Computing	Computation and devices are all around us	Decentralised computing, diversified networked devices	Information is accessible anywhere through any device
Proactive Computing	Anticipates user's actions, acts proactively	Constantly monitors and analyses the user's context and learns patterns	The human is taken out of the control loop
Intelligent Environments	Unencumbered interaction with non-computational objects	Brings the computer into the background	Enabling natural forms of interaction between humans and computers
Mediated Spaces	Understands and participates in multi-person interaction	Many sensors and processing required to understand interactions	Changes our perception of computers and the way we use them
TUT definition	A space that is capable of adapting and reacting to user's actions	Networked devices, sensors, actuators and controlling systems	An adaptive, relaxing environment which enables straightforward control

The remaining sections of this chapter present additional terms that are closely related to smart environments and compares smart homes to home automation.

2.8 Internet of Things

Internet of Things (IoT) is another concept that is based on the assumption that in the near future every device will have a unique identifier, e.g. network address [EPoSS08]. Having multiple networked devices around us creates a ubiquitous computing environment that is able to exchange data, context information and processing capability. Whereas the current situation around the Internet is that unique IP-addresses are starting to run out, the newer version of the IP protocol, IPv6 [IPv6] holds 3.4×10^{38} addresses, which should be sufficient for the foreseeable future. Thus, a future IoT can be significantly more heterogenous than the current Internet due to the vast number of different devices that are connected. The Internet today contains devices that are somewhat standardised and similar, mostly person-

al computers, servers and network gear. However, if every toaster, toothbrush and armchair is added, the nature and requirements of the network will be quite different. The IoT scenario also contains a few dilemmas: ubiquitous intelligence cannot be accomplished unless communication, protocols and interfaces are standardised and made compatible with each other. Additionally, there is a fundamental design issue regarding the nature of the interconnected device network, whether to design it as a centralised type using a central node or completely distributed with intelligent, independent network nodes. As wireless devices become increasingly numerous their management must be taken into consideration. Changing batteries can no longer be an option, and other ways of powering devices must be found. Current RFID technologies are able to supply power wirelessly over short distances but there is more promise in energy harvesting technologies, where devices extract energy from their environment. This is accomplished, for example, by collecting solar power, kinetic energy or energy from ambient heat. Thus, in theory, the device can operate without maintenance or any external electric power supplies or wires.

IoT can be defined as *"Things having identities and virtual personalities operating in smart spaces using intelligent interfaces to connect and communicate within social, environmental, and user contexts"* [EPoSS08]. IoT is predicted to become reality in 20 years as miniaturisation progresses, power consumption of devices decreases and devices become more autonomous. IoT does not only comprise devices inside a home but is everywhere around us; outside, in the car, in the office and at home.

2.9 Seamless Computing

When a ubiquitous computing environment contains a multitude of services, computers and UIs, it allows users to access information anywhere in any form. The concept of seamless computing [Kawai04] implies that computers and networks work together without difficulty and can offer users the optimum services and UIs anywhere and anytime. Data that has been input at some point must be always available from any access point, and similar content should be accessible even from different kinds of devices. Apart from obvious compatibility with computers and devices, seamless computing requires free roaming access between networks, resource sharing among computers and protocols that allow service discovery and ad-hoc networking. A seamless transition is one that involves a potentially disruptive state change (such as when moving from a desktop computer with one OS to another with another OS and different versions of other software), yet hardly distracts the user [Satyanarayanan05]. For example, when a user with 3G mobile phone moves from an area with 3G reception to an area where only traditional GSM networks are available, the phone will automatically switch from 3G to GSM networks without the user noticing anything.

However, seamless computing is facing constant difficulties due to the tremendous pace at which new technologies, networks, protocols and devices are introduced to the market. Standards do exist but they quickly become obsolete when newer, improved versions emerge. Autonomous computing [Ghanea-Hercock02] could be one possible solution to the problem, by introducing evolution and the capability for growth into computer systems and software.

Mahadev Satyanarayanan et. al. [Satyanarayanan05] propose an architecture called ISR, Internet Suspend/Resume, which works in a similar fashion as the suspend/resume action in a laptop computer. This would allow users to work on a workstation at one location, suspend their work and walk to another location where they can resume their work without interruption. The work would simply have transferred to another location, and the user does not have to carry any hardware. Many users are already familiar with the suspend/ resume action of a laptop, and since ISR would work in a similar fashion, it would not require users to familiarise themselves with new practices.

2.10 Context Awareness

The concept of context is vital to humans in everyday communication with other humans, but in the case of digital computer communications almost all of this information is lost [Dey01_1]. Body language, ambient conditions, people around us, sounds, odours, etc. are all information that humans process instantly without noticing. In contrast, a computer would need lots of sensors and processing power in order to do achieve this. Contextual information could, however, add significant value to human-computer interaction, increasing its richness and providing better services. In smart environments it is possible to utilise sensors around the space, making it theoretically possible to detect contexts in the environment. Therefore, a context-aware system can follow the actions in a space, detect contexts and provide relevant information and services to the user. The real challenge lies in selecting which sensors to use and what kind of information is important for detecting contexts. Experiments have been made to detect normal everyday scenarios, such as dining, watching TV and bathing using hundreds of different kinds of sensors [Logan06], and results show that it is difficult to reliably detect a certain scenario. Even a small variation in sensor data might cause the detection algorithm to think that another scenario is unfolding, or falsely detect another scenario.

Context ambiguity is also a potential problem among context-aware applications that assume the sensed and interpreted contexts to be the same [Dey05]. Ambiguity is caused by problems in interpreting sensor data and converting it into context information, for example if a speech recognition software fails to catch an important phrase or a positioning system reports incorrect coordinates. According to the author, handling ambiguous contexts requires user involvement, thus helping the system to correct false detections and assist it with learning contexts. In order to perform this, UIs need to be able to provide redundant mediation techniques (allowing the user to choose the least obtrusive and most suitable UI for interaction) and flexible input methods (related to both time and space). Regarding user involvement there is also the matter of availability and discretion [Nagel04]; when can the user be contacted and when should the system be silent? In a study by Kristine Nagel, a case of context-mediated communication, the knowledge of user availability is made known to trusted parties before any communication or interruption of the user is attempted. The goal was to find out if it is possible to accurately predict the availability of users in a home environment. According to the author a home environment is especially difficult in terms of knowledge of user availability. Availability is dictated by three principal factors: co-presence (are there other users present, and is there currently any interaction between

them?), location (where are users located?) and activity (what are the users currently doing?). For example, a user in the kitchen might be cooking and occasionally available for interaction, but if she is washing dishes her hands are wet and interaction has to be limited to verbal or visual means. The greatest variation, however, is caused by individual habits and preferences. Different people have different specifications for when and where they are available, and these preferences can vary enormously from person to person. One user might consider the bedroom a place for undisturbed rest whereas another user might regard it as a place for relaxation where the user is always available. Parenthood can also drastically change opinions when full attention is turned towards the baby and everything else is of secondary importance. Availability is also dependent on time, again with great variation depending on the user. There are also different levels of interruption, for example urgent items that require immediate attention or casual items that can be attended to later. Naturally the level of urgency also affects the threshold of user's availability. The researchers used a pager that sounded randomly to discover what users were doing at a particular moment and how available they were, and how willing they were to be interrupted in various scenarios. The research was primarily conducted through interviews.

The context that a context-aware system is processing must be a composition of relevant information gathered from the smart space [Mark99]. A structured, indexed recorded interaction is of much greater value than a simple log of all recorded activities and sensor readings. It is also vital for referencing future interactions in the space by providing an inferential representation of what has been happening earlier. By encoding the current and relevant past states of the context the system is able to communicate with users regarding their current activities.

Where accurately detecting contexts is difficult, so is learning new ones. If every slight change in sensor readings would cause a new context do be detected, the total number of different contexts will quickly rise to unmanageable levels. The choice is either to let people verbalise the contexts themselves (e.g. "I am eating"), or just let the computer assign ID numbers to them in a database. Initially, manually naming each context will require significant effort from users but eventually the number of new contexts (and thus, also the number of required user interventions) will decrease.

Context awareness allows the home control system to aid users in matters of safety, for example, if a fire breaks out [Mayrhofer04]. Accidents and hazards might be avoided if the system could detect dangerous situations and take preventative action. Dangerous situations could be fire, medical emergencies or less serious matters such as a network overload or disconnection. Other advantages concern configuration and preparation; if the network structure or device configuration changes, there could be another way of retaining functionality without affecting performance. Furthermore, if the system predicts that the user is about to return home, it could boot up the computer or preload some information, so that everything is ready. Alarms, calendar entries and automatic timer settings would be done in a similar fashion. With the help of auditory UIs, the interaction between the user and the system could assist in planning daily chores.

2.11 Home Automation vs. Smart Homes

Smart home technology has often (incorrectly) been considered a synonym for home automation, thus giving the impression that the home is an automated entity that performs all kinds of services for its occupants. Home automation can, however, be integrated into a smart home and be a part of the system.

The primary role of home automation is to make our life easier by controlling mundane functions like heating, air conditioning and lighting and allowing users control to set the parameters and threshold values. Additionally, home automation can manage and control the home when the occupants are away by taking over certain routine and tedious tasks that are easy to automate. Home automation systems can be rather simple in function, but reprogramming or reconfiguring such a system might require the services of trained support personnel. Some systems only include basic threshold or timer settings, with more advanced options requiring reprogramming or additional control units. The simplest form of home automation would be a heat regulator that would keep the temperature in a room within specified limits.

Home Automation is generally considered to consist of applications with certain pre-set operations, some with programmable options and the most sophisticated including robots and complex machines [Gann99]. Typical home automation applications include lighting control, security systems and home surveillance, home entertainment, irrigation and temperature control.

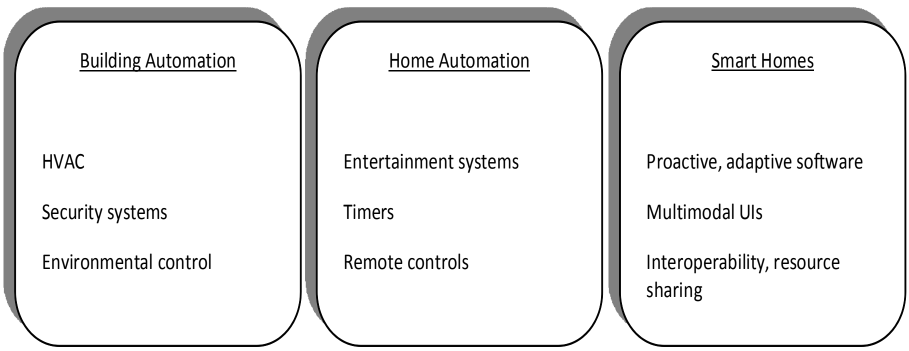

Figure 2.3 Classification into building automation, home automation and smart homes.

Where home automation concerns computers and devices that contain information technology, building automation is more related to the physical building, e.g. building management (security, monitoring) and environmental control (lighting, HVAC controls). A home automation system would, for example, turn down the heat inside the house when users leave the home for work, but it would not be able to adapt to the users routines or predict what time people come home. A smart system would learn that users come later than normal on the first Wednesday of each month because they go to visit their grandparents, for example, and it would also take into account the variations in outside temperature

and the effect of sunlight. Thus, the goals of home automation and smart homes can be considered to be the same at a basic level (making life easier and more comfortable). However, the number of tasks the automated home is able to perform and their impact are inferior to those of a smart home. Furthermore, an automated home brings with it new controls, settings and functions that users need to learn, whereas a smart home aims at making control of the home easier and simpler.

Most homes already contain some form of automation, such as lamp timers that turn on lights when it gets dark outside, electric outlets that can be switched on with remote control etc. The basic technology is no longer expensive, and there are many manufacturers to choose from, and people can even perform the installation themselves [Automation]. Home automation systems benefit largely from simple inexpensive networks, such as X10 [X10], since these are also easy to retrofit into older buildings. In other cases sensors and switches usually require direct wiring to a controller unit, and audio/video signals are transferred using traditional digital or analogue cables, possibly even wirelessly. Costs start to rise when touch screen wall panels, remotely controllable thermostats and multi-room audio systems are installed [Cybermanor, Homeseer].

3. Smart Homes

With electronic components becoming cheaper, faster, smaller and more efficient there has been a huge increase in the amount of electronic devices that play a part in our daily lives. Digital convergence presents us with new opportunities and accelerates the speed of the information and communication technology (ICT) revolution [ISTAG06]. Today our homes already contain many kinds of electronic devices that we use every day, usually without even noticing that there is a computer or an electronic system inside it performing measurements, calculations and adjustments. Thus ordinary everyday objects can contain functions and potential that are currently just beginning to emerge. As these (often computer-based) powerful ICT systems penetrate our lives, their effective and dependable configuration and integration becomes ever more challenging [Tiresias08].

In the worst case every new device has its own user interface, operational logic and functionality that users have to learn. Trying to manage all devices, making them work together and attempting to transfer data or information between them can prove difficult or even impossible. All this creates additional frustration, stress and problems, the very opposite of what such technology is supposed to deliver [Koskela03]. Indeed the motivation behind the design of smart homes is to reduce stress and improve the usability and living experience of the people living there [Weiser96], making their lives easier. Smart homes should also avoid automation and instead assist users in controlling their environment [Intille02], making the user a supervisor, not a controller.

The emergence of smart home technology, however, is not entirely without problems. One problem is that new kinds of technologies and new applications are introduced to the market with no consideration of their usefulness in real-world scenarios and everyday life. Thus many technological innovations are available but they have not been designed to work in the various scenarios where they could be used or together with other available technologies. This lack of a common standard for connecting different home appliances creates compatibility and interconnectivity problems. Furthermore, everyday realities and human factors are rarely considered in the design process and thus render the technology incapable of adapting to changing circumstances and varying user requirements [Leppänen03]. Current versions of smart homes have also been criticised for being solutions to problems that do not exist [Mäyrä05], giving rise to the claim of technology push rather than consumer demand. Even the term “smart home” has been criticised on the grounds that it implies the user is stupid. The term hints that the users are incapable of performing the most mundane tasks in their own homes [Leppänen03] and are reduced to the role of sitting on a sofa watching TV. Suggested alternative terms have been “media home”, “adaptive home” or “helpful home”.

There is, however, a good example in the form of the modern car of an application where embedded electronics, software, sensors and actuators all work together [Leen02]. A modern car is a fully integrated smart environment that monitors conditions both outside and inside the vehicle and attempts to make the ride as comfortable and as safe as possible for the driver and passengers. A variety of networks connect all sensors and controls together

and a computer controls actuators, offers UIs and adapts to the driver's driving habits. Lower speed networks manage simpler tasks such as opening doors, adjusting mirrors etc. whereas networks for more latency-critical applications connect to functions such engine parameter adjustment and stability control. Car electronics have indeed become ubiquitous, with drivers unaware of their existence until they are activated or applied. For example, the anti-lock braking system (ABS) adjusts the braking power so that the tires keep turning and the Electronic Stability Control (ESC) automatically applies braking power to the wheels to prevent the vehicle skidding.

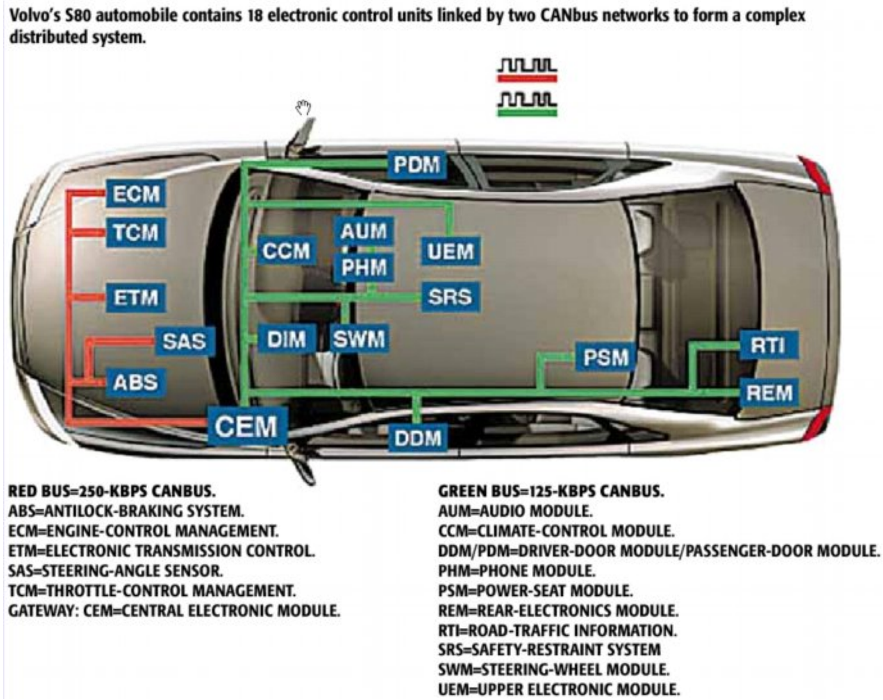

Figure 3.1 Example of the complexity of the electronics in a modern car. Photo: Volvo

In-car electronics raise another issue regarding computer control, automation and action/reaction: there are cases where a computerised system can perform significantly better and faster than a human and vice versa [Tennenhouse00]. Figure 3.2 below illustrates the various situations where it would be better for a human to relinquish control to the system. The first example (a) is a situation that would require very precise adjustments and much concentration from the user. For example, when cutting metal with a milling machine a computer controlled (CNC) machine is capable of achieving precision far superior to that of any human being. The second example (b) is the opposite case where events change very slowly and monitoring becomes tedious. It might also be difficult to notice when something goes awry, and in such a case a computerised control system would be better as it does not fall asleep or allow changes to go undetected. This could be applicable to temperature adjustment, for example. Example (c) is a case where an event occurs place extremely fast and reacting to it is beyond human ability, for example activating antilock brakes or inflating an airbag in a car. The last example (d) is a situation that involves sev-

eral variables at the same time, making it difficult for a human to comprehend and cope with these simultaneous events.

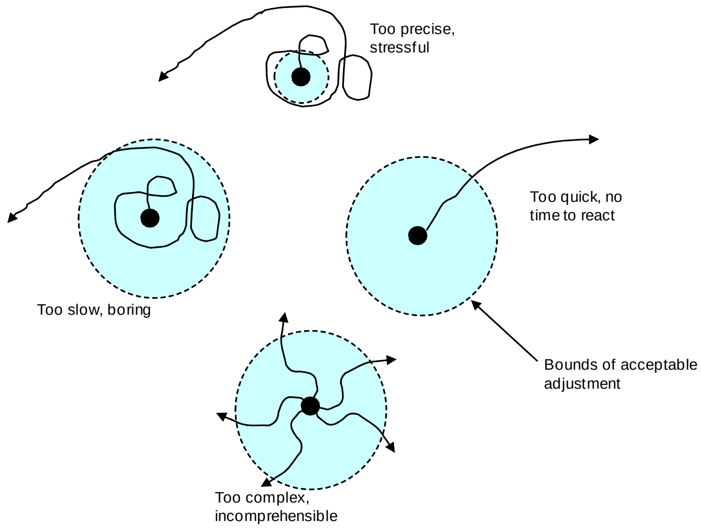

Figure 3.2 Different cases where computer involvement would be preferable.

These cases make it clear that there are certain situations where it would be beneficial to have a control system managing certain items in the home. This view is also one shared by the Tiresias research group, [Tiresias08] who propose that “The goal of equipping the home environment with technology isn't just to automate all the tasks that are carried out by the residents. The objective in design is to provide tools and services that empower and enable people themselves to address their social, rational, and emotional needs. Equality, autonomy, and control are the goals of empowering design”.

This chapter presents a brief history of smart homes and provides a glimpse of what the future might bring with it. There is also discussion of smart homes as physical spaces, design issues and the advantages and disadvantages of smart home technology.

3.1 Building Smart Environments

The space in which a smart environment is set up naturally plays an important role in the design process. In the case of a home a major obstacle is the way in which people regard their homes; the home is usually considered a very personal environment, almost sacred, where any intrusion or modification might be considered unacceptable [Koskela04_1]. In practice, however the home must be the installation space for all equipment so that there is little choice as to where all the infrastructure will be located. With unobtrusive installations and ubiquitous computing the equipment itself can be made as invisible as possible to the user, making it feel like a normal part of the home. This is not such a challenging task as it may at first appear since people gradually grow accustomed to electronic devices.

When people no longer notice these devices or realise that they are actually using them, the devices become ubiquitous and thus "invisible" to the user.

Normally newly-built homes contain little or no smart home technology at all, even if installation would simple to incorporate during construction of the building. During the design phase it would be relatively easy to make changes to the infrastructure, home networks and electrics but the customer is rarely consulted at this stage. The later changes are made, the more they will cost to implement [Tiresias08], and typically this happens after the customer has already moved in. Inevitably, home networks need cabling ducts, equipment needs installation space and sensors require both. Additional mains sockets and network connectors can also be very useful when more equipment is added. The structures in the building itself can contain embedded sensors and other means for monitoring conditions and events both outside and inside. For example, humidity and temperature sensors can alert users of imminent humidity damage, and external temperature and light level measurements can notify the system of hot weather and that extra ventilation or air conditioning will soon be required. With such sensors it can become easier to monitor the condition of the building and take preventative action against damage. Energy can also be saved if these conditions can be accurately predicted or quickly reacted to. New materials, such as self-monitoring concrete and self-healing structures can asssist in maintenance tasks whereas thin, foldable displays and wallpaper that can function as a display all can change the way in which people interact with the smart home. With innovations like these, the distinction between user interface and infrastructure can almost disappear.

Problems arise when new devices and networks are installed in old buildings that lack any infrastructural support. Thick, solid walls or metallic structures may prevent or hinder the use of radio communications, and even if wireless networks are used devices still need a power supply, which usually means a transformer (and power cables) or at least batteries. However, it is possible to utilise existing cabling in the building using appropriate communication equipment. Phone lines and power lines are already being used for networks [Gerhart99], and they can significantly reduce the need for additional cabling. In most cases these only facilitate communication, not control, since motors, actuators and relays are still needed for controlling the home. Adding new wiring or making changes to the electrical network however can be very challenging and expensive.

Another interesting problem arises when considering what happens when people move from one smart home to another. Already today there are differences between countries and cultures regarding the items that people consider to be fixtures and items which they take with them when they move house. The situation becomes much more complicated when thinking about smart home technology. There can be major investment in the network infrastructure, sensors and other fixed installations and if users take these with them (spending considerable time on dismantling the system) the home becomes a shell with no functional infrastructure, even the electrical network can be dysfunctional. On the other hand, if every apartment in the entire block is fitted with a similar or common infrastructure there is little doubt of ownership.

To enable control of electrical appliances and lights in a home it is feasible to wire the electrical cables using a star topology, making it possible to control individual wall sockets and

lights. The electrical switchboard can then be fitted with relays and a networked controlling apparatus, such as LINET [LINET]. This makes it possible to control lights and sockets not only from wall switches but through a network and from multiple locations. All lights can be controlled from a single location, making it possible to group lights and create master on/off controls for turning on or off all lights in the home. Traditional electric control networks, such as X10 [X10] also offer control of electrical equipment, but it also needs adapters and transceiver modules for control of home electrics. One advantage is that a light can be directly controlled without needing relays or extra installations if screw-in socket modules (see Fig. 5.48) are used.

In apartment buildings a practical limitation arises from the fact that it is rarely possible to control the heating and ventilation of a single apartment. In large buildings such facilities are centrally controlled, and users have only indirect or minimal control of the temperature in their home by opening windows and closing doors, etc. Only air-conditioning or limited temperature controls are usually available. This lack of control presents problems for controlling the home, as HVAC controls would be very useful for regulating conditions inside the home to implement the energy saving features that smart homes could offer. On the other hand, in apartment buildings a control network would also make it possible to centrally monitor security, energy consumption and environmental conditions using networked devices and sensors. In the case of a detached house, the situation is simpler: the HVAC system can be modified for advanced functions and flexible programming, giving users greater control of all functions that the infrastructure supports.

3.2 Design Challenges

The challenges for the smart home as a platform for compatibility and integration of fundamental components involve the diversity of the networked devices and the robustness of the system as a whole [ISTAG03]. Since a smart home must accommodate almost every device connected to the home network, special care must be taken during the design of the smart home platform. Heterogeneity of devices, compatibility and security are crucial issues in the process. Privacy and security are also important issues since devices can access private or otherwise delicate information regarding users and their surroundings. A smart home can collect large amounts of data related to user's activities, personal preferences and personal data that could be misused to endanger the privacy of the occupants. It is also important to note that wireless networks can also be accessed from outside the home and that mobile devices can be exposed to unsecured foreign networks where they might be compromised.

Marketing smart homes also presents certain problems of its own. Most people have only a vague idea what to expect or demand from future living, so it is reasonable to suppose that there is a good deal of uncertainty as to what a smart home could actually be like. For many users even the scope and capacity of today's technology can seem like science-fiction. In 2004 the research group for technology and everyday life (TATU) at TUT conducted research into how people envisioned future living, smart homes and what they would like to see in the near future [TATU04]. According to the report the concept of a future smart home is rather unclear, and people tend to use mental impressions to envision certain

smart home applications and ideas. In the study a group of people were interviewed about the features they would like to see in a future home, and what they thought about smart homes in general. They were also asked about their willingness to invest in certain technology and services related to smart homes. Factors affecting the level of investment include how exciting the product or service is, how useful and how mature it is considered to be and how innovative it seems. Also willingness to invest in installations on new buildings was considerably higher than in existing buildings.

According to the study the most desirable feature related to home security. Fire alarms, water damage control, home appliances that automatically switch themselves off, home monitoring systems and remote alarms were among the five most popular features. The table below shows what percentage of the 1800 respondents were “very interested” when presented with various smart home applications. It is noteworthy that only one per cent showed interest in using the Internet to control their home.

Table 3.1 The most desirable smart home applications according to the TATU research report of 2004 [TATU04]

Smart Home Application	**%**
1. Fire extinguishing system	55
2. Water damage prevention system	55
3. Home appliances that shut down automatically	48
4. Remote alarm system	41
5. Home surveillance system	36
6. Automatic climate control	35
7. Backup power system	33
8. Anti-burglar system	32
9. Telecommuting/distance learning facilities	23
10. Energy consumption monitoring	22
...	...
39. Controlling the home through the Internet	1

Fear of burglars and property theft is the foremost issue whereas personal security was considered less important in this context. The next preference is technology related to building automation, HVAC and energy management. Home entertainment, communications and multimedia appear relatively lower down on the list, which is interesting because this field is where the most rapid developments are being made.

3.2.1 Networks and Software

The requirements for a smart home network are rather demanding; it has to be reconfigurable, self-organising, dependable, secure and consume minimal energy. New algorithms for inter-device collaboration and communication are needed and the coordination between the artificial intelligence and reasoning software is also difficult to implement. The smart home platform should be easily scalable and it should be able to migrate tasks inside

itself and perform load balancing of the network. Resource management, for example locating all temperature sensors inside a room and gathering their measurements, is a very important feature, especially for more critical services, such as alarms and environmental controls. Load balancing and fault tolerance become important when there are power outages, malfunctions or network problems or part of the network is not accessible.

As mentioned earlier, compatibility (or the lack of it) is another major obstacle to the seamless integration of devices and networks. Even with adapters and converters some functionality might be lost or altered, possibly leading to other problems. There might never be a universal general smart home protocol for all devices and this must be considered when smart homes are being implemented. In practice this means that a smart home system has to be able to support a large variety of standards and there also has to be room for future expansion.

Software for the smart home has to be written differently to current standalone applications. Smart home software architecture is comprised of multiple embedded software components that interact with each other and the amount of different modules, agents and databases can be large. Thus the way in which software is currently written, using partitioned abstraction layers with fixed interfaces connecting them, is no longer a viable option. Software systems are also usually vertically integrated with fixed linkages between components, making it difficult to adapt to new interfaces and performing horizontal integration [ISTAG03]. As a result, writing software that is open to new components and that adapts to new situations and anticipates behaviour will be the main challenge for the future.

Chapters 6 and 7 discuss smart home networks and software in greater detail.

The IST advisory group has created a list of five technology requirements for Ambient Intelligence and present some possible future development scenarios for the year 2010 [ISTAG01].

Requirement 1: Very unobtrusive hardware

The increasing pace of miniaturisation and integration will allow electronics to be packaged into even smaller sizes in the future, paving the way for nanotechnology and Micro-Electro-Mechanical Systems (MEMS). At the same time the tasks and processing that the units are able to perform increase, and the integration of sensors, actuators and interface systems will result in the creation of smart materials. One key requirement for future AmI hardware is the ability to harvest energy from the surroundings, thus minimising the need for external power supplies. Very low-power wireless radio links also help to keep energy requirements low. When AmI hardware is designed the process should be focused on human factors and usability to enable the creation of a coherent AmI landscape instead of having only a group of networked computers.

New materials and display technologies make it possible to create seamless interfaces, with new ways for users to interact with their environment. This way it is also possible to create sensors and perform measurements that are unobtrusive to the user. No external de-

vices that require strapping on or wearing are required; all necessary electronics will be integrated into garments and other devices or locations around the user.

Requirement 2: A seamless mobile/fixed communications infrastructure

The complex heterogeneous network structure in a smart home needs to function seamlessly and reliably, no matter what kinds of hardware it is connected to. Wired and wireless communications need to be completely integrated and dynamically managed, so that devices do not require any configuration when they are moved from one network type or location to another. Plug and play or similar zero-configuration protocols take care of integrating a new device into the network, relieving the user of the tedious set-up and configuration tasks.

Requirement 3: Dynamic and massively distributed device networks

The AmI network scenario is a mix of static and mobile devices, in massive numbers. According to the AmI requirement they must all be able to access and process data from anywhere in the network, which requires a centralised or distributed database where all data is stored. This brings the focus on data and storage management that extends beyond middleware and system software. New standards and protocols are needed in order to create an adaptive embedded intelligence.

Requirement 4: Natural feeling human interfaces

New ways of interacting with the smart home also bring new challenges for human-computer interaction. Intuitive UIs allow users to communicate using gestures, speech and other natural ways, whereas artificial intelligence can use similar ways of communicating back to the user. Multimodal, multi-user and multipurpose UIs also present new challenges for UI design, as UIs have to be able to filter information, extract contextual information and present different kinds of content. Different kinds of signal processing, such as pattern and speech recognition, also become important when information is being filtered from sensor data. In order to attain seamless interoperability machine-machine interaction must also be intuitive and suitable for cross-platform operations.

Requirement 5: Dependability and security

In order to achieve a safe, dependable and secure AmI environment testing and verification methods have to be developed. Both physical and psychological issues have to be taken into consideration, and the system must also be secure against deliberate misuse. Self-organising and self-testing software might provide some relief on the software front and assist in the verification phase. Different kinds of user identification (e.g. biometrics) also introduce the need to secure sensitive and private data.

These requirements seem reasonable and important issues to be considered in the design process. However, these requirements were written in 2001 and as it is almost 2010 a short update might be interesting, as it would seem that many requirements can still not be met. For example, smart materials, MEMS devices and energy harvesting are not common in

today's hardware, but on the other hand integrated sensors and low-power radios are widely available. Seamless networking and compatibility has not been realised either, users are still required to cope with WLAN encryption keys, Bluetooth device pairing and incompatible data formats. On the UI front some advances have been made, for example capacitive multi-touch touch screens and touch pads allow users to control devices with hand and finger gestures, and this trend seems to be spreading quickly to all kinds of mobile devices.

3.2.2 User Requirements

Users of different ages and from different demographics have different abilities, desires and needs, and these must all be considered in the smart home design process. However many products today are not customisable to the needs of individual users, being designed for the average user and the mass market. This limits the adaptability of the product, its flexibility and popularity in the long run [Lehto98]. People's attitudes also differ with regard to technology adoption. Some, such as early adopters, appreciate having the latest technology in their homes and cars while others fear or mistrust anything new and unfamiliar [Tiresias08]. Security, privacy and safety are the major concerns of users. People are also concerned about reliability, long-term durability and the time it might take for a long-term investment such as a smart home to repay itself. The willingness to invest in smart home technology can also vary greatly according to the demographic classification of users. For example there is the so-called "second youth" or "third age" which involves people who have recently retired and are experiencing new interests and more free time. In many cases these are consumers with spending power and free time to devote to new hobbies, activities and services.

The most important user requirements for smart homes are:

- Customisability (the system can be modified to suit the needs of its users)
- Improved usability (improved ways of interacting with the smart home system)
- Safety (increased safety for the users, less things to worry about)
- Privacy (sensitive information and data must be kept safe)
- Consistency (UIs and systems should work in similar, logical ways)

A smart home should offer something for all, either in the form of adaptivity or modularity, as the greatest advantages can be achieved by customising the system to its users. For youngsters different kinds of entertainment and communication are important and for parents additional safety can be achieved with security and monitoring facilities. For example, unused electrical outlets can be turned off in the children's playroom, the kitchen stove can only be controlled by the parents and balcony doors are not left open and certain functions are not accessible from the home UIs. For elderly people and the handicapped smart homes can enable them to enjoy life at home without requiring special assistance.

The benefits of new UIs in this area are particularly apparent because users may be incapable of using all appliances from their own UIs, reaching switches or reading small font text. Reminders, auditory and visual UIs can bring the functions of the home close to hand

for such users. In general control interfaces should be close to the location where they are needed; a sophisticated control tablet mounted on the hallway wall will probably only be used when people are entering and exiting the house, in other cases its accessability can be a hindering factor. Another important issue is the difference between solutions that are useful in a work environment versus those that are useful at home. Something useful in the office may not be so useful in the kitchen or at home with children present [Aldrich03]. Unfortunately, most computing equipment and the way we interact with computers are designed and optimised for office use.

Consistency and predictability are also important factors for ensuring smart home owners feel secure and relaxed. Users should be able to anticipate the actions and functions of their homes so that they feel comfortable with the various events and activities taking place around them [Mäyrä05]. If consistency is lost it can lead to users becoming frustrated and confused, as the application or device is not doing what the users are used to expect.

Table 3.2 below shows examples of what kinds of requirements different age groups might have, what benefits they could have from smart homes and what kind of technology would be required to fulfil these requirements.

Table 3.2 Requirements and benefits for different age groups.

	Requirements	**Benefits**	**Technology**
Infants	Safety, monitoring	Infants cannot access certain dangerous functions	Surveillance, access control, controllable electrics
Children	Safety, entertainment	Safe play at home, children can use some functions of the smart home	As above
Youngsters	Entertainment, communication, efficiency	Customisable controls, distributed data, remote access	Distributed UIs, home networking, mobile systems
Adults	Usability, communication, efficiency, security, entertainment	Remote access, easy management of the home, cost savings	As above, energy consumption monitoring, sensor networks
Pensioners	Communication, accessibility	Improved usability and management, cost savings	Sensor and communication networks, remote access
The elderly	Safety, accessibility	Ability to stay at home without further assistance	Sensor networks, biosensors, communication networks, remote access

An interesting workshop study [Green04] set out to discover the kinds of concerns people had about the introduction of smart home technology. One primary question concerned cost: how much would installation of such equipment cost, how much would it increase the price of an apartment or a house, how much energy does it use or how much could it

save. Reliability was also important for the panellists since largely negative experiences of personal computers had made them question the reliability of such technology. Backup systems and manual overrides were thus also considered as necessary features. Security, privacy and safety were all grouped together as the third most important item, followed by ease of use and flexibility. Simple, intuitive easy-to-use controls should be used and the system should be able to adapt itself to the changing lifestyle of its users.

Before smart home prototypes are tested with real users some means of prototyping and verifying the concept would be helpful. Since AmI environments consist of multiple devices and UIs, it is no longer sufficient to test or commercialise single applications or devices [ISTAG03]. Instead the environment has to be considered in its entirety, consisting of interoperable architectures and interacting components. A method to achieve this is Experience Prototyping [Buchenau00], which concentrates on users' interactions and experiences rather than technical functionality. For example, instead of focussing on a lamp as a physical item and its functionality, the designer would concentrate on the light as an experience and how it affects the space surrounding it. Experience Prototyping is valuable for communicating ideas to an audience, understanding existing user experiences and context as well as exploring and evaluating design ideas. It simulates important aspects related to relationships between people, objects and environments. By allowing other people to directly engage in testing it gives everyone a shared point of view. Experience Prototyping enables researchers to understand user experiences and their contexts while new designs are being evaluated, and testing can be done either in a laboratory environment or in more realistic surroundings. New tools, such as 3D modelling, allow easy visualisation of prototypes and environments and provide the possibility of quickly modifying the environment and performing user trials inside the virtual environment.

3.3 Benefits That a Smart Home Can Offer

The motivation behind the creation of smart homes is to improve the quality of living, make life less stressful and enable people to spend more time with their families. From general safety, ease of use, customisability to remote user interfaces smart homes have much to offer.

Ease of Use

Probably the greatest advantage smart homes offer is the ability to flexibly control the home. New UIs, communication interfaces and seamless interconnectivity make it possible to use multiple locations for controlling a single device, and group controls make it possible to control of several devices at once. Customisable menus further enhance usability and make it possible to create personalised UIs for each user, group controls and save personal preferences. Multimodal UIs allow interaction between the user and the system to be more natural while also providing a variety of feedback from the system for the user. When new devices are introduced they are made easier to use because they can be controlled from familiar UIs. Zero-configuration capabilities allow them to be easily connected to the home network with little effort from the user.

Safety

People sometimes leave home having forgotten to turn off an appliance and then must return home or call another family member to rectify the situation. Such situations not only increase energy consumption but can be hazardous if they involve the risk of fire or other danger. A smart home with remote control facilities makes it easy to control lighting and monitor home appliances from a remote location. Similarly, it would be possible to turn off electric outlets in the nursery and disable control of possibly dangerous home appliances (e.g. the kitchen stove) when children are present.

Energy Savings

Major topics of current interest in domestic living concern energy saving and monitoring consumption, and the ability to effectively control appliances and HVAC - related devices in order to help users to reduce energy consumption. YIT, a large Finnish construction company, has installed water usage meters in each apartment of a block to study the effect this has on water consumption [YIT]. The results showed a reduction in water consumption of one third. When people were able to monitor their water usage continuously it was easier for them to try different water saving techniques and directly see the effect on consumption. Another study [Homesoft04] has shown that during the entire lifetime of the house 20 % of the cost of living is composed of construction costs whereas the remaining 80 % is for maintenance, heating, etc. Thus, though a smart home would cost more to build, in the long term it could achieve greater savings. A smart home could save energy by turning off unnecessary lights and appliances, by reacting quicker to variations in ambient temperature and by using daylight to collect as much energy as possible by adjusting drapes and window shutters. Further energy savings can be achieved by allowing the home control system to lower temperatures by a few degrees and turn off unnecessary ventilation and lighting when people are not at home. In office buildings the savings could be even greater, since they are generally only occupied eight hours per day.

Communication

Communication with family members also becomes easier, people can leave notes to each other using home UIs, for example on a display in the kitchen or near the front door. Communication to remote locations outside the home, for example to relatives in another city, is also possible using home UIs, cameras and broadband networks. A study made by IST [ISTAG03] shows that today's urban populations are becoming increasingly isolated from friends, families and neighbours. The quality of social bonds is, however, relevant to the well-being of people and thus of great importance. By building environments that support the formation and maintenance of social networks it is possible to reinforce these important bonds. The Arabianranta residential area in Helsinki Finland contains homes for around 10 000 people and it is built around a virtual community with many on-line services and a common Internet portal [Arabianranta]. This "Virtual Village" is an experiment involving third-party services, discussion forums, on-line calendars, bulletin boards and eServices. Each apartment is equipped with a fiber-optic high-speed Internet connection and wireless networks are widely available throughout the residential area. The goal of the Virtual Village is to experiment with community networking and the effects of pervasive con-

nectivity and the impact this has on the inhabitants and their lives. The purpose is to discover if networks make people more social or isolated, and how much connectivity is actually desirable. In such a case pervasive communication technologies can enable users to choose when and with whom they want to socialise, making it easier to suit the requirements and needs of the individual.

For the elderly and handicapped it would also be beneficial to provide other ways of interacting with equipment in the home. Wheelchair-bound people would benefit from a wireless context-aware controlling device, which would allow them to easily open doors and control lights. Elderly people would again have reminder functions, health monitoring and suitable UIs that would make their lives safer and more comfortable. Health care management in a smart home would also involve family members, friends, professional medical staff and the local community.

Adaptivity

The ability to adapt to changes in lifestyle, living habits, routines and other circumstances is another major advantage of smart homes. Physical adaptivity and modularity of the home is an important matter, but the possibility to tailor and adjust the settings of the behaviour and functions of the home are at least as important since they dictate how the home reacts to different situations. After all, family size is quite likely to change over the years, the abilities of users can change or users might simply wish for different experiences. Certain details can be profiled and specified when the system or equipment is purchased but subsequent changes must also be possible without the need for expertise in programming or hardware engineering. Adaptivity is also important for the comfort of the users by letting them modify the home into a pleasant living environment.

Interaction

In addition, since a smart home contains several kinds of user interfaces and is capable of many kinds of feedback there are numerous ways of interacting with users. This interaction can be used in many ways to enhance the experience and activate the user: for example, the system can alert the user to items requiring attention or to potentially dangerous situations. It can be used to relay interesting information (e.g. display or read aloud news headlines or e-mails) or even to establish a casual dialogue between the user and the system. All of this naturally depends on the complexity and capabilities of the artificial intelligence in the software components of the smart home.

Table 3.3 summarises main benefits from smart home technology and also lists related challenges.

Table 3.3 Summary of smart home benefits.

	Driving Force	Main Challenges
Ease of use	Improved usability, remote control UIs, natural interaction	Zero-configuration protocols, automatically reconfigurating UIs
Safety	Added safety for users, remote control and monitoring	Privacy, dependability of the system
Energy savings	Cost savings, environmental impact	Increasing efficiency, implementing energy saving features
Communication	Healthcare issues, staying in touch with relatives, social aspects	Choosing the right communication methods, knowing when people are available
Adaptivity	Changes in lifestyle, personal preferences	Modular design, adaptive software
Interaction	Feedback to the user, personalised experiences	Programming AI

3.4 Reliability

Ideally any networked system should be stable and sufficiently reliable to run 24 hours a day, but in practice there will inevitably be periods of downtime for various reasons. Networks may be down, blackouts may occur, software can crash or a mechanical or electrical fault can disable parts of the system. In a home environment uncertainty is to be expected of a smart home system that connects everywhere and controls all appliances, lights and sensors in the house [Koskela04_1]. Indeed a widespread concern about smart homes is what would happen if the controlling computer crashes or if there is a blackout. Problems with computer software, instability, bugs etc. have understandably caused people to worry about using such technology in their homes. People are also somewhat mistrustful of a system that does things behind their backs [Tiresias08], and instead they prefer to remain in control of decision making in their daily lives. Complete control could be handed over to the system only when there is nobody at home, letting the system take care of lights, security and temperature control, for example.

A worst case scenario would be a completely computer-controlled environment, with all UIs and functionality tied to graphical and electronic interfaces. In this case, if a crash or network problem occurs all functionality is likely to be lost and users would even be unable to turn on lights or open doors. Even minor faults can be difficult for users to diagnose because several faults can cause similar problems. Finding out which device has a flat battery, which one has lost its configuration data or which one has completely locked up can be confusing for users.

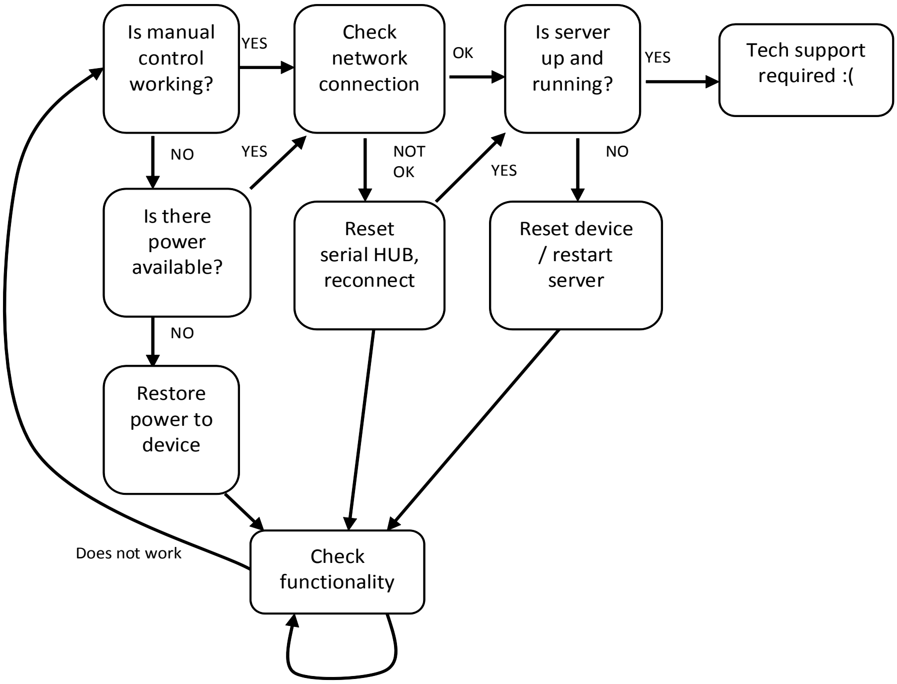

Figure 3.3 Flow diagram of troubleshooting a device in the Smart Home.

Ideally, nothing should happen if the central system or network goes down; the home should function as before, only without computer control and graphical UIs. Home appliances can still be used from their own UIs and other controllable devices can function with traditional manual controls. The Smart Home at TUT has been designed according to this philosophy. In the case of an electric blackout very few devices will function in a modern house, and a backup battery for the server will be of no use if there is no power for lights, motors or home appliances. The term "graceful degradation" was coined by Adam Greenfield [Greenfield06], to describe a situation in which a fault in a part of the system it should only be apparent to the user as the loss of some minor part of functionality instead of a complete breakdown. For example, if a porch light bulb is broken it would still be possible to have some light outside by turning on the light in front of the garage, instead of the system only attempting to turn on the broken light and doing nothing else.

Most humans have a fear of losing control, and thus users should always have the option of manual control whenever they wish. This is also desirable from a practical point of view, as it is possible that the nearest UI is out of reach or unavailable [Aldrich03]. It would also be beneficial if functions, timers and automation could be easily disabled by a single keypress, and then quickly re-activated if necessary; there are always situations in which even the most sophisticated neural networks, algorithms or adaptive systems fail to function properly. For example, a scenario involving TV watching can be carried out in so many ways that there can easily be a situation when the context is recognised incorrectly. The TV can be on in the background, users can watch a movie and opt for a darkened living

room for better viewing, the TV can be on for playing console games etc. In the case of an incorrect context, the lights can be turned off in a bad situation or telephones can be inadvertently muted.

The concept of smart home upkeep also arises in the context of the reliability and serviceability of modern electronic systems. Reliability is an issue in terms of the overall reliability of the smart home and its dependence on the reliability of its components. The image of the weakest link determining the overall strength of the system also holds true for a smart home system. Furthermore, a smart home system should not be so intrinsically complicated that it would require expertise to set up and use, though inevitably there will be a need for such skill, particularly during initial setup. Later when the system is in use users should be able to add new devices and functionality by themselves. There will probably be a need for third-party service to update, maintain and monitor the home system if the customer prefers. This kind of "eJanitor"-service would remotely monitor the state of the home system, provide users with information (such as electricity consumption, advice on energy saving, statistics etc.) and user support. This would allow users to ignore the underlying technology and concentrate instead on using the smart home system. However, an obvious drawback of such a service would be the costs involved and any delays in obtaining the service in the event of a serious problem.

3.5 Mobility and Mobile Computing

As people move around in their homes they are able to access information anywhere. But instead of having people going to a specific location to access information a more flexible solution would be to make information available everywhere. This is where mobile computing has a role to play. Typically, mobile computing is considered as a situation where mobile users use mobile devices, for example PDAs, laptops or cellular phones [Forman94]. However, as noted in the introduction, mobile computing that takes place outside the home lies outside the scope of this thesis.

Mobile computing can also mean that information itself is mobile and in search of an ideal place to store and display itself. Certain information might be suited for display on a certain UI or it might be better suited for storage at a location where it will more likely be needed. A smart environment can recognise users and analyse their activities while at the same time fetching data that is relevant and interesting to the user. In such a scenario, users are not required to carry any information on their person since everything is stored in the network. This, however, requires the infrastructure to understand and utilise the services and the capabilities of all devices in the network. Devices must also have the capacity to inform the network of their capabilities and the services they offer. Furthermore, the requirements for a mobile node are rather high as it must be able to store and process data independently if it is disconnected or out of range of the network infrastructure [Sentilla07].

According to Nokia’s vision [Nokia08_1] mobile phones will play a major role in mobile computing in the near future. Phones can communicate with other nearby phones, share information and extract sensor data that they continuously gather. Accelerometer data is

used for detecting movement and gestures, microphones for detecting voices and sounds and various radio receivers for analysing weather conditions, etc. Information gathered from a large group of users could be used to detect and predict traffic jams or even epidemics.

Another approach to mobile computing is to make the entire home mobile [Case01]. Relocating houses has been commonplace, for example, in Queensland, Australia, where mining towns and associated businesses were often relocated as mines became exhausted. Physically dragging houses by tractor could be replaced by common house foundations that can accept a variety of structures, making it easier for families to relocate and housing types to be changed rapidly according to the residents' wishes. Houses could be built on stilts, allowing them to be easily removed and transported elsewhere. Plans to utilise older buildings in a similar way are also under way, saving them from demolition and also reducing restructuring costs.

3.6 Adaptive Systems, Learning

Smart homes are usually tailored for specific applications or to fulfil the requirements of the inhabitants [Edwards01]. Modifying the system at a later stage (for example, if the house is sold or if there are changes in lifestyle or situation) can prove difficult and costly. An adaptive home monitors the actions and reactions of its users and keeps track of what they have done in each situation. Eventually the system becomes trained to the routines and behaviour of its users and can take over some functionality of the home. In an ideal case, the users will no longer need to worry about manual control and device management.

Usually adaptivity fits into the middleware software (see Chapter 7) that controls the home, placing it between the home UIs, home network infrastructure and devices [Dommel05]. Using various algorithms, for example pattern learning, or by correlating interactions between users and devices, the adaptive software builds a database to support itself when actions or changes are detected. This information is then used for determining whether something new has been learned or if it was something that had previously been learned. More complex systems, such as the Adaptive Home [Mozer05] (see Chapter 4**)** utilise neural networks for self-programming and artificial intelligence.

3.7 Business Perspective

The emergence of smart homes offers new business opportunities for companies in many industries. The market is changing from the traditional supplier/developer model involving manufacturers of electric household goods and construction companies into the current model which also accommodates "brown goods" companies (i.e. home entertainment and IT industry). In addition to these, certain types of service providers offering various support and maintenance will play an important role in the future [ISTAG03]. Classification into different market segments and specialities is becoming difficult because the distinction between hardware and software is no longer clear, making it more difficult to exploit and promote products. In some cases the growing ICT industry has brought large benefits

and economic growth, as in the case of South Korea. Current plans include a complete ubiquitous city, the u-City [Jeong07] that will link traditional industries together with the ICT industry, converging technologies to form a ubiquitous network of information, services and content. Similar plans exist in Oulu, Finland, where sensor networks, new kinds of information access and urban interactions are being integrated into the city environment [Ojala08].

From a business point of view there are many factors that affect the value of smart home technology compared to traditional technologies [VTT03]. The user would be interested in energy savings, additional value from home systems and user interfaces, safety and the resale value of the property. Status and image issues can also affect the willingness to invest in smart home technology. Additionally, the cost of possible third-party services become important, especially if they involve long term commitment. Application developers and device manufacturers, on the other hand, view value gained from smart home technology from a different perspective: they care more about bringing new products on the market or developing existing products to suit the new smart home scenarios.

The danger is that proprietary solutions remain on the market and slowly kill off the idea of a networked smart home. Already today there are multiple competing standards (both open and closed) and there is no clear “winner” that would become a de facto choice as far as smart home networking implementations are concerned. One major reason for this is the sheer amount of standards that designers have to choose from. Instead, open standards and developer forums would give opportunities for everyone to enter the market and develop compatible products. This would also help researchers because there are often many independent groups researching and developing solutions for the same problem, with little knowledge of what is being done elsewhere in the world.

When a particular part of smart technology is being designed, care must be taken to ensure that the smart home in its entirety is considered and not only small individual items. As with many other applications, the value and usefulness of a product may not be realised until it is integrated and tested in a proper environment. However, this often gives rise to a chicken and egg problem since a particular application or appliance might have no use until there are services providing content or context for it to function. Thus collaboration between different parties and developers is of crucial importance.

3.8 Smart Home History and Future

Projects related to smart environments and smart homes have been conducted since the 60s, but collaboration between man and computers has a much longer history. The emergence of new exciting technologies paved the way for innovations for both everyday chores and entertainment whilst stimulating the mind. Science fiction books and TV series envisioned of robots, talking computers, large video screens and other gadgets that seemed quite far-fetched at the time. However, it did not take long for the Smart Home concept to emerge, something that happened in the 1980s with certain enabling technology already available a decade earlier. Light switches that operated by clapping the hands, computer networks, adjustable thermostat heating etc. were already a step closer to the reality of the

computerised home. One notable milestone was the formation of a “Smart House” interest group at the National Association of Home Builders [Aldrich03].

The following section briefly presents the history of the smart home and the advance of domestic technology since the beginning of the 20th century.

3.8.1 Early Smart Home Projects

In 1945, after World War II Vannevar Bush wrote his article called “As we may think”, in which he reflected upon the post-war situation [Bush45]. After the war there would again be freedom for researchers to continue their studies into peaceful applications. However, he foresaw one particular drawback: there was already a plethora of research and results being published worldwide that it would be very difficult to keep abreast of all the new information. In order to speed up communication and make information more widely accessible, he envisioned the need for new technical innovations such as automatic typewriters, innovations in photography, speech recognition and a device he named the “Memex”. The Memex (the name was derived from memory extender) was for storing personal information, such as text, notes, images and other items of interest. This device would make information easily accessible and manageable, acting as an extension of the human memory. Bush’s work includes many other innovations that have already come true, but there are also some that still await implementation.

One early report from 1962 [Englebart62] concerns the increasing complexity of everyday problems and the rate at which these should be solved. New ways of improving the human response to these problems are studied and analysed. One solution is to increase the intellectual effectiveness of humans for example by augmenting it with computers. This was well before the emergence of the personal computer and other “personal electronics”.

Much later came the Intelligent Room at MIT (1998) [Coen98], an early laboratory space (a former meeting room) for bridging computational and everyday activities. The Intelligent Room was not intended to be a ubiquitous computing space full of computers as it was designed with minimal hardware modifications and also enabled interaction with non-computational objects. This was achieved by the use of wearable infrared badges, pressure sensors in furniture, computer vision and speech and gesture recognition systems. Cameras are used for tracking people, identification and UI control, whereas the speech recognition system is used for controlling the system and receiving auditory feedback. The authors concluded that it was difficult to obtain reliable output from the different kinds of sensors in the Intelligent Room using contemporary technology, especially the cameras and computer vision system. The ambiguity inherent in human gestures also presents problems when trying to determine a user’s intentions.

The Classroom 2000 project (1998) [Abowd96] set out to enhance the teaching and learning experience of university students. The goal of the project was to discover how ubiquitous computing technologies can be used to improve education. For this purpose electronic white boards, tablet pads with a pen UI and web pages were used. Technology was used to support students before, during and after the lecture.

Other Smart Home projects are presented in Chapter 4.

3.8.2 A Brief History of Domestic Technology

During the 20th century there has been a tremendous increase in domestic technology. Chores that previously had to be done by hand could now be assigned to machines and appliances and thus more spare time was available and the way people used the kitchen changed for ever. Most of these advances can be credited to electricity and, later during the century, to information technology. After the 1940s the focus became very technology-oriented, mostly on different kinds of machines, automation and technology. In the 1970s information technology took over, with computers and networks emerging. It was not until the 21st century that the users' living experiences became central issues and more user-friendly development started.

The technological development during the 20th century can be roughly divided into five periods [Panzar00, Aldrich03]:

The period from the early 1900s to the 1920s were pioneering times for modern home appliances and new electric appliances. The home was still very traditional and old-fashioned: running water and mains electricity were far from being universally available. Development was driven by the shortage of a domestic workforce and industrialisation, which was to result in the emergence of middle-class citizens.

From 1920-1940 mass produced, standardised home appliances were becoming commonplace, and the 1933 Chicago world's fair introduced Mankind to new stunning visions of new home appliances and all possibilities that they had to offer. Electricity was becoming commonplace, although it was still primarily used for lighting. The development was seen as a process whereby science contributes to new inventions that industry brings to the market. The user's job was simply to start to use these inventions and to adapt to their requirements. The new home appliances actually created more chores than earlier, since these were now easier and faster to do. This resulted in clothes being washed more frequently and the house being cleaned more often.

After the war women had grown accustomed to work in industry, and now formed an important part of the workforce. Media propaganda tried to persuade women to stay at home again by running traditional housewife campaigns and promoting family ideals. The modern kitchen started to evolve, with design focusing on accommodating all the new home appliances on the market. Refrigerators, washing machines, vacuum cleaners and electric stoves were all making their breakthrough. The late 1950s were however plagued by pessimism and changed attitudes. The flood of new inventions like jet airplanes, cars, television and nuclear energy made people believe that all significant inventions had now been made and there was nothing more to invent. The laws of physics were becoming apparent when it came to speeds of cars, aircraft and communication. The telegraph was as fast as electric communication can be, faster cars could not move people around any faster on the congested highways and personal flying vehicles did not emerge either.

Later, in the 1960s and 1970s everything changed again. There were new visions about robots, artificial intelligence and electronic brains and the future seemed bright and interesting. The role of the traditional housewife changed for good, and women were now making careers outside the home. New appliances, such as food processors, electric razors and hair dryers, sewing machines etc. were flooding the markets. Thermostats, central heating and limited degrees of home automation also emerged. In 1969 the ARPANET, a project between the US department of defence and Massachusetts Institute of Technology, became operational. It was the world's first packed-switching network, which later evolved into the Internet. A network was needed, because computers were very expensive at the time and researchers across the country needed a way to exchange information and data.

In the 1980s and 1990s colour television made its breakthrough, and video recorders were soon to follow. Microwave ovens, tumble dryers and cordless phones became common in every household. Home entertainment was revolutionised with the Compact Disc, game consoles and cable television. Where the PC had originally been given a role in archiving, communication and accounting, it later proved to be more popular for gaming, entertainment and Internet usage. When different kinds of smart home projects started the computer already had an integral role in the home, a role that continues to evolve.

As in the past, whenever new electrical home appliances were marketed to housewives, the primary marketing argument was that these new appliances leave users with more time to do something else. Later on, as time-consuming home entertainment devices came on the market the time saved doing chores faster could now be spent relaxing with a vast choice of entertainment.

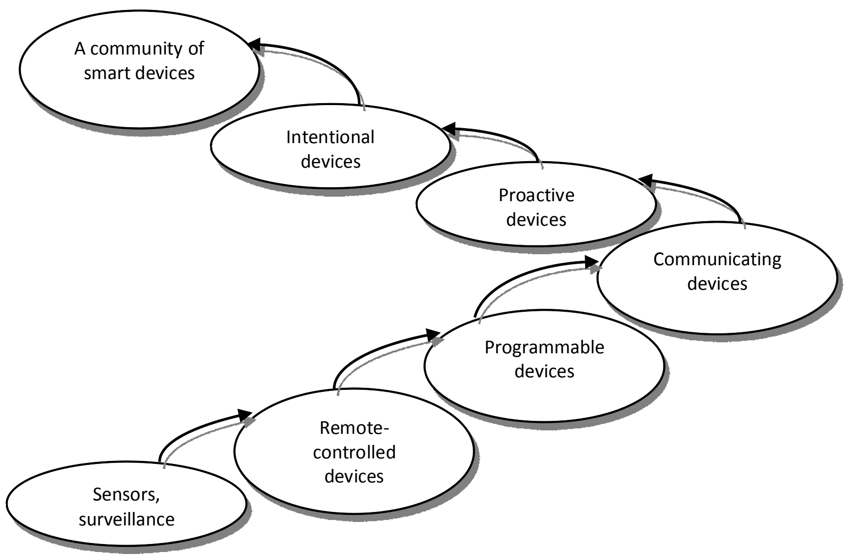

Figure 3.4. The evolution of a smart home [Panzar00]

3.8.3 Future

Discussion about the future of homes, human-computer-interaction is a very interesting topic. Microsoft's scientists have given much thought to how we interact with computers and information technology in the year 2020 [MS07]. The report suggests that the way we feel about technology in our lives will probably change considerably in the future. Younger generations will be accustomed to using IT from an early age and ubiquitous computing will become part of childhood and school life all up to adulthood. Increasing connectivity enables us to keep in contact even over longer distances, and the communication between people can change radically. The boundary between humans and computers can move ever closer towards the human body (for example with implantable and wearable technology) with the boundary between computers and the surrounding world will shift towards the environment (pervasive and distributed computing). The computer we know today will be very different in 2020.

On the negative side, the ever growing amount of interconnected devices makes it increasingly difficult for users to understand the workings of a system, and thus also how to react to problems. The lack of understanding might lead to less confidence in the case of new technology, something that can be observed already today.

How the growing dependence on technology will affect our basic skills and lifestyles remains to be seen. Will humans become too dependent on computers, or can artificial intelligence become so integrated in our lives that we no longer require the same amount of thinking and action that we need today [Norman93]?

The home as a physical place can also face changes in the future. The ongoing drift of people from the countryside to the city continues to create a need for affordable urban housing and since there are many kinds of families and lifestyles it is difficult for a generic apartment to suit all these needs. The apartment of the future might be modular and flexible with shared spaces that inhabitants are able to use. In order to further facilitate flexibility, rooms can have multiple functions, for example the living room could easily be changed into a bedroom for the night.

4. Related Work

4.1 Overview

Smart home projects, laboratories and industrial showcases exist all over the world, and while some might be more advanced than others, they share many similarities. Generally smart home projects contain some form of network infrastructure, often with wireless networks, sensors and actuators. Graphical or multimodal UIs are used for controlling the home while some kind of middleware software manages decision making and automated tasks using artificial intelligence, agents or pre-set rules. Signal processing with the help of cameras or location sensors is used for locating and identifying people. Depending on the research group, the aim of the project can be to prove the functionality of particular technological innovations, to gather usability information and practical testing results or to demonstrate the latest commercial technology.

This chapter reviews research projects that have produced practical data and real-world results (i.e. they are similar to the smart home projects at TUT), their goals and findings and relates them to TUT smart home research.

4.2 Other Smart Home Projects

4.2.1 Telenor Fremtidshuset (Future Home) (2001-2004)

Telenor, a Norwegian telecommunications company, built a complete house in the former Fornebu airport area as a flexible living laboratory [Nyseth04]. The Future Home, completed in 2001, was designed to allow researchers to explore the possibilities and ideas with new technology in private homes. It was also designed to accommodate several guests for demonstration purposes. For this purpose the home was fitted with a LON works infrastructure and 1-wire sensor network, allowing users to control home appliances, heating, etc. The walls were also reconfigurable and there was ample space for equipment. Several user tests were run in the Future Home, involving communication technology, emotional responses and media usage among family members. The Future Home also experimented with emotional UIs (window blinds controlled by stress levels of users) and odour UIs (a certain odour in the home would indicate a need for communication, for example the mother wants her children to call her). Another research topic involved distributed families, i.e. employing flexible rooms and communication technologies to help children feel relaxed when moving from one home to another.

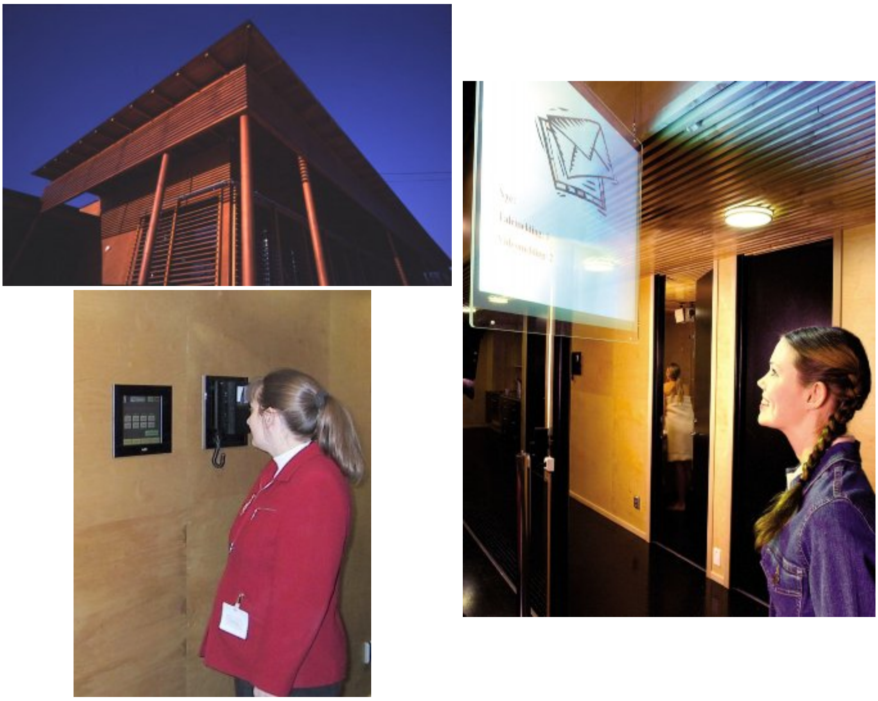

Figure 4.1 Telenor Fremtidshuset. Photos: Telenor archives / author.

4.2.2 Philips Home Lab

Philips research group in Eindhoven, Netherlands, have built a research lab for testing Ambient Intelligence solutions [Philips]. The Home Lab is a fully equipped home, used for testing prototypes in a realistic scenario with the latest technology. The laboratory features speech recognition and user positioning along with several screens for displaying information. In order to study how users behave in the laboratory, microphones and cameras are mounted in every room. Tests were conducted with family members, friends and youngsters, who were able to share digital media and discover new ways of interaction. Philips' vision is that convergence will continue in the future, leaving users with fewer individual non-compliant appliances. A TV set will contain everything needed in the living room, from a digital receiver, amplifier, and speakers to a media server. Equipment can be controlled in new ways using gestures and speech commands, leaving the user free for other activities at the same time. Some of the technology that was tested in the Home Lab is already available in current products.

Figure 4.2 Philips Home Lab. Photos: Philips Research.

4.2.3 The Adaptive Home (1999)

The Adaptive Home was an experiment with adaptive technology in a home environment [Mozer05]. A house in Colorado, USA was fitted with HVAC and lighting control, numerous environmental sensors and actuators. The control system was based on neural networks and used reinforcement learning and prediction techniques to create a learning home control system. In other words, in contrast to automated homes that are programmed by the users to perform certain tasks the Adaptive Home programs itself. The Adaptive Home was designed to adapt to users' everyday lifestyle patterns, thus helping them save energy and enjoy increased comfort. In time, as the system has collected sufficient information, the home can anticipate the users' needs and act proactively. The system could optimise the house heating according to times of occupancy, turn off unnecessary equipment and adjust lights and temperatures to suitable levels when users came home. This design also made the house less dependent on user interfaces, as users can continue using light switches and other manual controls to train the home.

Figure 4.3 The Adaptive Home. Photos: Michael C. Mozer.

4.2.4 Georgia Tech Aware Home (2000)

The Aware Home is a complete house built by Georgia Institute of Technology in Atlanta in 2000 to research emerging technologies and services [Abowd02]. The home has been used for testing, experimenting and evaluating state-of-the-art technologies related to future living. Projects in the Aware Home are aimed at simplifying management of the home, assisting in everyday activities and entertaining family members during their leisure time. According to the researchers, technology should be introduced into the home without major disruption of lifestyle (relaxing, enjoying things together as a family etc.) and without becoming a burden to the users.

As its name implies, the Aware Home is designed to be aware of the people inside it, where they are and what they are doing. A tracking floor sensor array can monitor the movements of users inside the home and trackable tagged objects make themselves easier to find. Another emphasis of Aware Home research is on aging residents and improving their quality of life by allowing them to remain in their homes and live independently. Research projects focus on solving the problem of using everyday technologies and on connecting family members together. In order to solve these problems new UIs and communication methods have been introduced. Family members can keep contact with elderly relatives using a variety of gadgets, children have new kinds of interactive toys and there are also various forms of home entertainment. Some personal items have RF-tags to make them easy to find when misplaced.

Figure 4.4 The Aware Home. Photos: Aware Home Research Initiative.

The Aware Home has two identical living spaces, each one consisting of two bedrooms, two bathrooms, an office, kitchen, dining room and one living room. The basement houses a control room and a shared home entertainment area. The purpose is to have people living in one half of the building while the other half is used for testing and prototyping. The Aware Home is used by both staff and students at Georgia Tech for multidisciplinary studies.

4.2.5 Microsoft Easyliving (1998)

Easy Living is another project where prototypes and architecture are being tested in a smart environment [Brumitt98]. Microsoft's emphasis is directed to data processing, modelling and combining sensor data modalities. The laboratory uses computerised vision with the

help of multiple cameras to detect and identify people in the laboratory and computer agents and models to control the space. Cameras are also used to track devices, while devices are tracked with tags or through RF networks using signal strength indicators. Controllable devices in the laboratory are computers, A/V equipment and lighting, which are controllable from graphical UIs on screens, in tablets or PDAs or using gestures and voice commands. The Easy Living Geometric Model maps devices and their relationship with the physical world and a middleware platform, InConcert, is responsible for message passing and device addressing. The Easyliving laboratory is an example of disaggregated computing, in which tasks are performed by multiple computing devices, such as PCs, PDAs, mobile phones.

Figure 4.5 The Easy Living laboratory. Photo: Brian Meyers / Microsoft Research.

4.2.6 MavHome (2001)

The MavHome is a smart home project at University of Texas at Arlington [Cook03]. The multidisciplinary research project attempts to view the smart home as an intelligent agent that uses sensors and actuators to achieve its purposes. The MavHome name comes from “Managing an Adaptive Versatile Home”, and the focus is to maximise the comfort of its users and minimise operating costs. In order to achieve this, the house must recognise and predict the actions of its users and adapt to their routines. For this purpose MAVhome uses several prediction algorithms. The MAVhome agent architecture consists of four layers; a decision layer, for executing actions based on information obtained from other layers, an information layer that gathers, generates and saves information that could be beneficial later, a communication layer that manages information exchange between layers, and a physical layer, which consists of physical devices in the smart space.

Smart spaces can provide users with automated features, energy savings, improved safety and security. According to [Youngblood05], a smart environment is able to gather information from the environment and use this and its knowledge on the inhabitants to improve the user experience. For testing purposes, the project has two test environments at the university, called the MavPad and the MavHome. A virtual counterpart, a simulated workspace, is also used for verification. The test environments are equipped with sensor networks, powerline communication for lighting, adjustable window blinds and HVAC controls. Sensors include light, humidity, smoke, temperature and motion, and they are

networked with a proprietary sensor network. Various learning algorithms, models and agent software are tested and simulated, and these are later verified in practice using the test environments. If the system works as planned, it will attempt to minimise the users' interaction with home devices. In other words, a functional smart home reduces the amount of adjustments and actions that users have to perform.

4.2.7 HomeSoft / LONIX smart home concept (2003)

HomeSoft was a Finnish software company that specialised in smart home control [Homesoft04]. In collaboration with LONIX, a supplier for LON-based home automation, it supplied smart home technology to one-family houses. HomeSoft went bankrupt in early 2006 and the future of the concept remains unclear. The idea behind the consortium was to offer customisable home automation packages, which would be delivered on a turnkey basis. The customer, therefore, would no longer need to consult numerous separate contractors (for heating, plumbing, electricity etc.) and try to make them work together. Instead the HomeSoft package would be negotiated only once since the contractors would be working under the consortium. The concept was intended to deliver comfort, safety and energy savings that small-house builders would find useful. The system included pre-set states, which could be changed from a wall panel switch; at home (daytime), at home (night), away, away (for a longer period of time), party. Each mode switches the home into a specific mode by adjusting lights, drapes, doors, HVAC controls and security systems to a certain state. Additionally the system could alert users of fire or water damage by sending an SMS as well as turning off water, electricity and ventilation when necessary. The system was designed to be controlled from wall panels and switches and also by means of remote controls and mobile phones or through an Internet connection.

Figure 4.6 Homesoft control UI.

The system was based on LON-based modules controlling heating, water, lighting and electrics using various sensors to detect changes in the environment. The software ran on a COBA-compliant [COBA] platform.

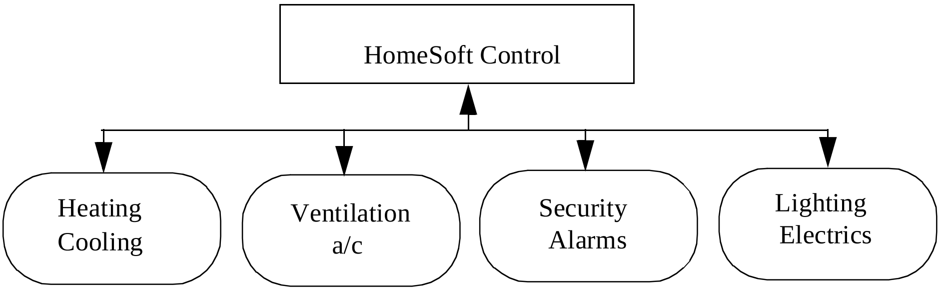

Figure 4.7 Example of building automation system integration [Homesoft04].

4.2.8 Duke Smart Home (2007)

The Duke Smart Home is a large "living laboratory", which also serves as a student dormitory at Duke's Pratt School of Engineering in North Carolina, USA [Duke]. It has been designed from the outset to function as a test environment where students can experiment and improve different technologies that the smart home contains. Students are also expected to create their own designs and also provide input on current installations. The project also has industrial partners seeking to strengthen the market for integrated smart home systems. The building contains a general area for relaxation, a computer lab, media room and student bedrooms. The key element in the design is energy efficiency, and many of the building's systems are based on this philosophy. Rainwater is collected for use in bathrooms, solar power is used for heating water and the building uses heat pumps for heating and cooling. Removable panels on the walls allow students to install and test new designs.

Figure 4.8 Duke Smart Home. Photos: Duke University

4.2.9 HP Cooltown (2001)

In 2001 Hewlett-Packard laboratories at Palo Alto developed a laboratory named Cooltown for ubiquitous computing. HP describes it as "*A vision of mobility, connectivity, com-*

munity, and transformation based on open standards and user needs" [Barton01]. One of the main themes in Cooltown is Internet connectivity; everyone, everything and every space is connected to the Internet and through which many kinds of devices can interact. HP believes that the Internet, or more specifically the World Wide Web, will be the context for future ubiquitous networks due to its openness and prevalence. The infrastructure consists of beacons, for example infrared ones, that contain contextual information about events, location etc. Beacons transmit specific URLs to mobile devices, which then obtain a web link where they can download relevant information. For example, when a user in the vicinity of a conference room where a meeting is about to start, he can download information about the meeting onto his PDA and decide whether or not to join in. This integration of the physical world and the virtual world of the web forms a sensor-enhanced ubiquitous environment as shown below.

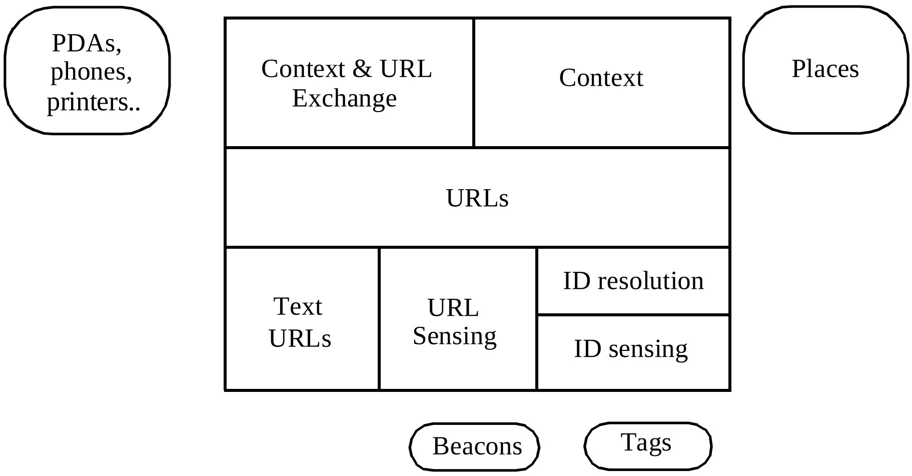

Figure 4.9 Component relationships, URL sources and contexts in Cooltown. [Barton01].

Cooltown laboratories have been built around the world, and they typically contain a future office setting, a digital home, large displays and mobile terminals for information access.

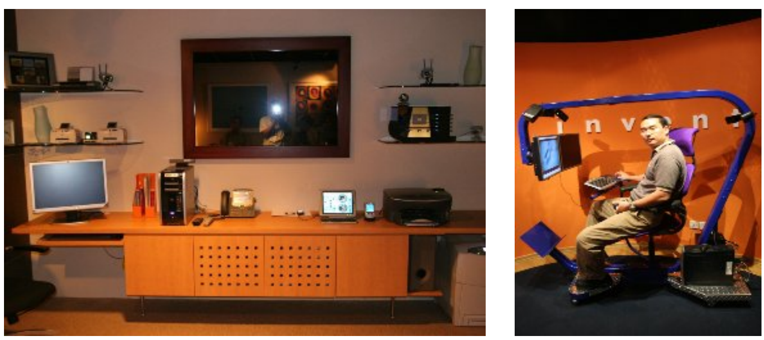

Figure 4.10 HP Cooltown. Photos: Anton Diaz.

4.2.10 Orange-at-Home (2001-2003)

Orange-at-Home was a smart home project started in 2001 by Orange, a UK mobile network operator. The project was a smart house in Hertfordshire, which was equipped with the latest technology. The Orange house featured health monitoring of its inhabitants, a self-diagnosing heating system, state-of-the-art entertainment with audio and video available in every room, motorised locks and lighting control. It was designed to function not only as a showcase but as a living laboratory with periodic user experiments. Families were interviewed before, during and after their stay in the smart house. The smart house contained seven different UIs, including wall panels, PDAs, voice commands, mobile phones and computers. The user groups ranged from people who were familiar with technology to those with little experience. The aim of the project was to gather information on how useful and usable users found the technology, with the ultimate goal being the launch of such technology on the global market.

Results from the Orange-at-Home project [Randall03] are interesting, and there are many similarities with the eHome project (presented in Chapter 5). Users in the orange house liked the ability to remotely control the home, and the feeling of being in control was also highly rated. Sometimes, however, the feeling (or illusion) of being in control and the feeling of losing control can sometimes overlap, depending on the design of the UI. Users had reservations about being monitored (it was considered intrusive), and there were also questions concerning control priorities; who is allowed to override the adjustments made by others, and how will personalised settings be affected if someone else is using the system? One significant result from the orange house was that users, as in the eHome, had a single preferred UI for each scenario. In other words, they also found it useful to have multiple UIs, each designed for its own application.

4.2.11 MIT House_n (2003)

Massachusetts Institute of Technology conducts research on home design and products and services related to future living. As such the House_n project is directed towards research into new technologies for all ages, proactive healthcare, biometric monitoring, activities of daily living, privacy and new construction materials and solutions. A research facility, the PlaceLab [MIT03], has been constructed at MIT to facilitate experiments related to the project. The PlaceLab is a 93 m^2 single-bedroom condominium, filled with sensors that can be used for studying people, their actions and reactions in the laboratory. The laboratory is periodically inhabited by test users who are remotely monitored by researchers in order to provide data for further analysis.

The PlaceLab contains several different sensors, embedded in various locations in the lab. For example cabinets in the lab contain sensor modules for measuring environmental quantities, infrared transmitters and microphones. Various sensors are installed in fittings such as cupboards, drawers, windows and furniture to monitor their usage. Video cameras and biometric sensors capture data about the users and their movements almost all the laboratory surfaces can be used to display digital information. New innovations in the lab are

structures created inside the Open Source Building Alliance (OSBA) [OSBA], which include easily deployable chassis beams that have ductwork, plumbing, power and signal cabling and mechanical attachments integrated in the structure. Such structures make it easier and faster to deploy and modify future homes. The House_n project is managed by the Department of Architecture at MIT.

Figure 4.11 PlaceLab and an OSBA prototype element. Photos: MIT.

4.2.12 MIT aire

Another project at MIT is the aire (Agent-based Intelligent Reactive Environments) [AIRE], which was devised to investigate the design of pervasive computing systems and applications. The aire project includes topics such as augmented spaces, speech recognition, perceptual sensing and distributed agents. During the course of the project several “aire-spaces”, or intelligent environments, have been designed, ranging from pocket-sized computers to large conference rooms. A variety of applications has been built around these environments, for example different kinds of visualisations, input methods and contextual reasoning.

The aire project forms part of MIT's pervasive computing project Oxygen [Oxygen], and there are currently two laboratories used for research into pervasive technologies. E21 is a conference room equipped with ubiquitous technologies, such as walls that function as both white boards and projection displays, cameras for detecting and tracking users, microphones, and an array of speakers that can be used for directing sound towards users. E21 is used for developing camera vision applications, demonstrations and meetings.

The aire project also covers intelligent workspaces, both from a physical and technological standpoint. It provides a dynamically reconfigurable test environment that adapts to new configurations using both hardware and software. The goal is to discover what activity a person is engaged in and whether the workspace could offer relevant assistance and maximise the work contribution.

4.2.13 MIT Oxygen (1999)

The Oxygen project of the Massachusetts Institute of Technology [Dertouzos99] started from the assumption that cheap electronics make powerful, affordable and small devices available everywhere. These devices exist all around us in the same way as oxygen. But instead of making people serve computers, computers must be made to serve people so that computation becomes human-centred. Oxygen had three goals; to introduce new technologies, to increase human productivity and to help people to achieve more while doing less. Interaction with computers is to be achieved through natural means such as speech and gestures, freeing users from traditional computer UIs and input devices.

The backbone of Oxygen is a wired/wireless “self-configurating” network (called Net 21), through which a vast amount of information and processing power is available. Devices that connect to Net 21 include Enviro21s, which are static computational devices (e.g. wall-mounted panel computers) and mobile Handy21s (smaller sized PDA- style appliances). Different kinds of automation systems that manage repetitive automated tasks in the environment, other systems enabling collaboration and various kinds of sensors are also connected to Oxygen networks. This allows users to access and search information in numerous ways, for example they can listen to a phone conversation they have had earlier at work while preparing a meal at home.

4.2.14 GatorTech Smart House (2004)

The GatorTech Smart House is a project run by the Mobile and Pervasive Computing Laboratory at the University of Florida [Helal05]. The Smart House is a programmable pervasive space designed to assist the elderly and disabled in their daily lives to make them more comfortable and secure. The goal of the project is to create assisting environments that are able to sense themselves and their residents and create connections between the physical space, intervention services and remote monitoring.

The Smart House runs generic middleware built around the OSGi platform [OSGi] that stores service definitions for all hardware (sensors and actuators) inside the home, in essence turning the Smart Home into both as a software library and runtime environment. The middleware is designed to be easily expandable and accessible by a third party. It is divided into several application layers; the physical layer (covers all physical devices in the home), sensor platform (converts physical devices into software services), service (OSGi framework that maintains active services), knowledge (reasoning engine), context management (detects and registers contexts) and application (associates behaviour with contexts) layers.

The Smart House building is located in Gainesville, Florida, and contains a multitude of smart devices. For example, the smart floor is for user tracking, smart plugs with RFID tags sense which appliance is connected to the power outlet, and the microwave oven detects what food is being cooked. The sensors contain a small amount of code that they transmit to the server, thus registering themselves in the network and providing informa-

tion on themselves. The server deals with context awareness and sensor data abstraction and performs adjustments according to decisions from the reasoning service.

Figure 4.12 GatorTech Smart House. Photos: University of Florida.

4.2.15 FutureLife (2000)

FutureLife is a one-family house located in Cham, Switzerland [Futurelife]. It was built in 2000 to demonstrate what smart home technology has to offer and provide an insight into future living. The house contains innovative applications, the latest technology and systems as well as a resident family of four people. FutureLife is probably the first smart home experiment with real inhabitants. Parents Ursi and Dani Steiner receive regular visitors to the house, and interested parties can also visit the project website for further information and webcam feeds.

The house contains hardware and applications from several companies, who have also provided most of the funding. The house uses the EIB bus for intra-house communications and controls, together with a "Fitbox" service provider portal that provides home automation controls and remote control facilities. The home also contains controllable lights, shutters, windows, doors and a front door with access control employing keys, fingerprints or wireless tokens. Control is facilitated through a wireless SIMpad tablet, speech recognition and web-based UIs. Energy savings are also important, and the house utilises fresh air ventilation by opening and closing windows in suitable weather conditions. Fresh food and goods are delivered to a Skybox, essentially a refrigerator, from a third party provider. The Skybox contains sensors for registering its contents, and users are able to order supplies from a wall-mounted panel as needed. The lawn is mowed by a robot and an automatic irrigation system waters the plants.

The Steiner family enjoyed the remote control facilities and the possibility of adjusting various parameters in the home. However, they also observed that “a few single appliances do add to the comfort, but the major point is to really have an effective use and added value is the network of different appliances, applications and services”, underlining the importance of the connected nature of the system [Steiner01]. The family was also reasonably technically proficient since they were able to make pre-set modes and create various macros that they used on a daily basis, such as a movie mode for the living room and ventilation

schemes for bedrooms. Sensors in the Futurelife home also contained a form of learning mechanism, allowing users to teach them various kinds of desired behaviour.

Figure 4.13 Futurelife house interior. Photo: Futurelife AG.

4.2.16 inHaus (2001)

The inHaus innovation centre of the Fraunhofer-Gesellschaft, located in Duisburg Germany, is a cooperation platform for new technology and innovations [inHaus]. The goal of the centre is to pool technologies from different manufacturers and integrate them into the inHaus centre. Other themes include reducing energy consumption, increasing the attractiveness of smart home technology and enhancing the convenience for senior citizens.

The facility opened in 2001 with the completion of the first building, inHaus1 The centre forms a 250 m^2 residential space consisting of a living area, home office, garage and garden. In the basement there is a mechanical workshop which serves as a location for hobbies and a place where researchers can develop software and test hardware. Technology allows work to be transferred from the workshop to the home office upstairs, making it possible to work and live under the same roof. The inHaus1 centre is used for demonstrations and technology development, and for studying how different systems interact and how they are accepted by users. It is planned that selected residents will live in the laboratory for periods from one to three months, after which user data and findings will be recorded. To date inHaus1 has resulted in a number of commercial products that are being marketed by inHaus GmbH.

Completed in November 2008, inHaus2 features the latest technology in energy saving, intelligent construction and building materials. The 3500 m^2 building is designed to be versatile and flexible so that it can be modified for numerous purposes. Planned applications include healthcare, hotel rooms and offices with research scheduled until at least 2011 with a budget of 27 million euros.

Figure 4.14 inHaus1 facility. Photo: inHaus-Zentrum.

4.3 Discussion

Previous sections present only a handful of all smart home research projects that are being conducted around the world, but they do represent the diversity and different areas of interest that have emerged over the years. These projects can be categorised into three subcategories: university projects, corporate projects and projects that have involved long-term user testing. University projects all concentrate on solving a certain problem by using the latest technology and methods available. The Adaptive Home became an adaptive space capable of learning with the assistance of neural networks, whereas the Aware Home again serves as a platform for several individual research projects, each focusing on improving our lives, communicating with family members, etc. MavHome relies on agents, actuators and sensors to manage the space and create a pleasant experience for its users, and the impressive number of projects at MIT include living laboratories, computer laboratories and conference rooms. The Smart House at GatorTech again concentrates on an open OSGi platform and elderly care.

Of these projects the Adaptive Home has been a pioneer in adaptive and proactive home control systems, and research on this subject is also being conducted at TUT. The Aware Home presents a complex and interesting smart home infrastructure, but the research consists mostly of small, independent projects and a complete home control system with appropriate UIs seems absent.

Research projects with a commercial background are naturally more inclined towards promoting new products, services and technologies. Telenor’s future home concentrated on communication technologies whereas Philips’ Home Lab concentrated on media sharing and home entertainment. Microsoft’s Easyliving laboratories demonstrated disaggregated computing, new kinds of UIs and home middleware, and HomeSoft with its home automation package attempted to make it easier for customers to customise and build the home of their dreams. Cooltown allows users to exchange URLs and context, bridging the physical world and the virtual world of the World Wide Web. The inHaus conglomerate in Germa-

ny integrates products and services from various companies into their innovation centre, with their first project concentrating on working at home.

Technology demonstrators and showcases are useful for increasing public awareness and for allowing users to have a “hands-on” - experience with technology, but often these scenarios are built around marketing new technologies instead of trying to solve a certain real-life problem. Thus it can take a considerable time before this technology becomes commonplace, and compatibility and upgradability problems can further inflate this problem.

There are not that many research projects that have involved long-term user tests, many laboratories have been inhabited temporarily, either by research staff or volunteers, but these tests have only lasted from a few days to months. The Duke Smart Home is also another living laboratory, but in this case there inhabitants are students and the laboratory their permanent home. The Orange-at-Home project experimented with different groups of people, both with and without technical backgrounds, in order to survey the usefulness and usability of new technologies. The FutureLife-house in Switzerland is an interesting case where the inhabitants are also partially the developers of the project, giving them unrestricted control over the home control system.

Short-term laboratory tests are more common, but it takes a longer time for users to start feeling at home and to feel comfortable and familiarise themselves with the new environment. As there are only a few research projects that have conducted long-term user tests it makes the research contribution from the eHome project significant. The Duke Smart Home seems a very interesting project, and the students are probably highly motivated to enhance their dormatories. Technology students, however, hardly represent average users, and similarly to the users in the FutureLife house they have skills and advantages that cannot be expected from the average resident.

4.4 Summary

As this chapter has shown, there have been numerous similar projects active during the past ten years. Even if they share much in common, each project has its own area of focus and interest. Smart home projects at TUT have also had their own special goals and properties, which from the beginning have been low cost, practicality and technical innovation. Networks have been implemented using existing technology and standards while almost all devices have been implemented and designed in-house. All designs have been built and implemented in a real physical environment. Usability and reliability have also been important criteria, and for this purpose experiments with several different kinds of user interfaces have been conducted, while at the same time traditional functionality has been retained in the form of manual controls. Later, as the research progressed, adaptivity and proactivity became important themes, with learning fuzzy logic-based home control systems. For the most part, telecom-related technologies and applications (e.g. broadband networks, video-on-demand, multimedia services etc.) have been ignored due to their heavy dependence on external services and the telecom industry. Healthcare, on the other hand, has been researched in related projects but has not played a significant role in smart home

research as such. Results from biosensors and other healthcare-related sensors can, however, be easily integrated into the smart home infrastructure.

The Department of Electronics also conducts research into smart clothing, and since this branch is not unrelated to smart environments, there are potential benefits to be gained from collaboration between both fields [Kaila05_1].

Smart home research projects at TUT are presented in more detail in the next chapter.

5. TUT Smart Home Research

5.1 Research Projects and Environments at TUT

For many years different kinds of research concentrating on intelligent homes, ubiquitous computing and home networking has been conducted all over the world, as presented in the previous chapter. Mostly, however, these have been theoretical studies in a mock-up or laboratory environment. And though this kind of research has been popular at universities and companies, there is still a vast amount of empirical study left to do.

To meet this need for starting constructive and empirical research on the subject we set out to implement physical devices and spaces instead of theoretical tests, simulations and interviews. Smart home research at TUT started when a simple low-cost network for connecting different devices together was designed and implemented. Later different kinds of sensors, actuators and other devices were built and all interconnected to form the basis of a smart home. The first test environments were located at Tampere University of Technology, and were later expanded to include an apartment with tenants for real-life studies.

This chapter presents four different smart home implementations at TUT, their initial goals, design and implementation. Each space served a slightly different purpose, enabling research to be conducted from many points of view. Fig. 5.1 presents the timeline, starting from 1999 showing important milestones, such as completion of my Master's thesis in 2001, on the way.

Timeline 1999-2009

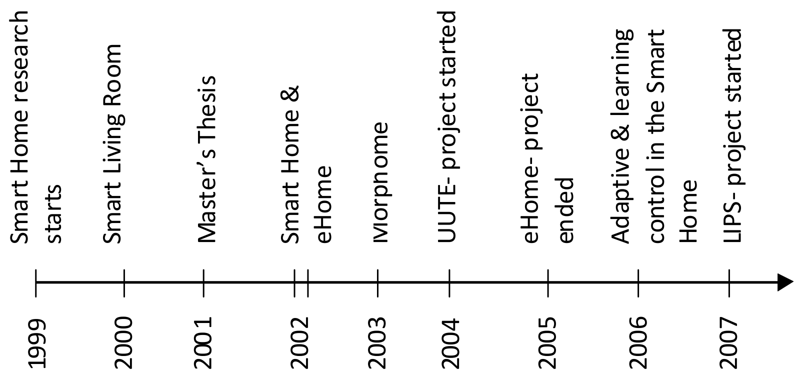

Figure 5.1 Timeline of smart home research at TUT from the author's point of view.

5.2 Smart Living Room (1999-2002)

When smart home technology research started in 1999 there was a clear need for an environment where the infrastructure, user interfaces and devices could be tested and installed. The goal of the Living Room project [Vanhala01] was to create a relaxing home environment with controllable devices, sensors and a user interface from where the home could be monitored and controlled. Another key theme was user activation, i.e. the system should notify the user of tasks that needed attention instead of automatically taking care of them [Mikkonen00]. By bringing user interfaces together to an intuitive common control UI better usability and easier control will be achieved.

Figure 5.2 The Living Room laboratory, showing the dining area, kitchen and living room.

In 1999, when the first smart home project was being started, the specifications for the first smart space were as follows [TUT00]:

"*From the beginning the emphasis of our research has been on creating relaxing, stress-free environments where the users don't have to worry about forgetting to turn off the lights or coffee maker, the indoor plants dying or other kinds of everyday things. Also, a high degree of automation was not desirable, since things happening behind the back of*

the user were considered awkward and confusing. Instead, things that required the user's attention were brought up by the home computer, and appropriate action could be taken. The space itself was designed to be relaxing, without a TV set, flashing lights or beeping computers."

For this purpose the Smart Living Room test apartment was built in early 2000. A former virtual reality laboratory was renovated and remodelled into a 40 m^2 apartment with a living room, vestibule and kitchen. A suspended ceiling allowed easy and unobtrusive installation of equipment and the space was large enough to have separate rooms and areas for testing. Because the laboratory room was located in the middle of the building it had no windows. In order to make the apartment feel more realistic and homely it was decided to build an artificial balcony in one corner of the living room. The balcony can be seen in the figure below, in the upper right-hand corner.

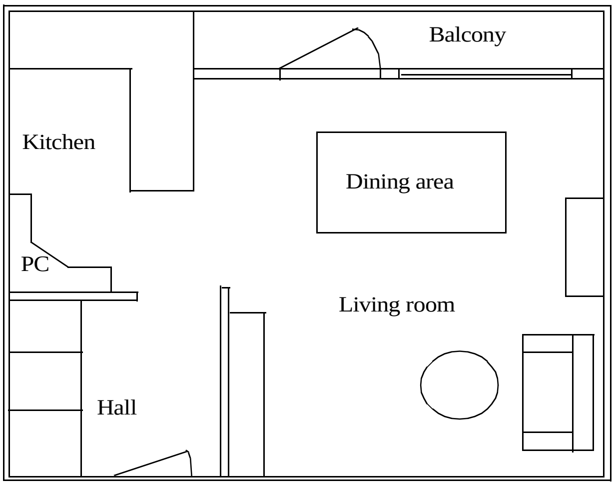

Figure 5.3 Layout of the Living Room.

According to our philosophy, the Living Room was designed to be a relaxing and a comfortable living space [Kaila01]. The living room was furnished with a comfortable couch and chairs, a dining table was placed near the windows and a small kitchen with a bar table was built in another corner. Lighting was accomplished with small halogen spots, which provided the room with warm ambient light. Before the laminate floor was installed, special EMFi - sensors were installed on the floor by VTT [EMFi]. These were to be used to monitor movements inside the apartment. The artificial balcony presented an interesting design challenge, as it was basically a narrow corridor separated from the living room. In order to create a pleasant view from the living room windows, a large poster with a view of downtown New York, was put on the balcony wall. A handrail was also built and two high-power artificial daylight lamps were installed in the ceiling. To further enhance the illusion of a city apartment, an ambient sound system was also installed. Speakers emitted random city sounds and background noise. With this setup it was possible to create artificial daylight and the atmosphere of a big city apartment.

Figure 5.4 Living Room dining area and balcony.

As the Living Room was intended to be a testing space with numerous controllable electronics, a central user interface was needed. For this purpose a miniature PC was embedded into a small coffee table and equipped with a touch screen and batteries. This UI was also intended to function as a multi-purpose remote control for A/V equipment.

Figure 5.5 Coffee table and embedded computer (right picture). Batteries are located under the lower surface.

Initial plans for network infrastructure were based on simple, low-cost solutions. Eventually serial RS-232 cabling was selected because it was widely available in off-the-shelf devices and microcontrollers. An infrared link was being constructed for wireless applications.

5.2.1 Living Room Network Infrastructure

The first network in the Living Room was designed around the tabletop PC. A serial cable link was used for lighting controls, there being no need for wireless because the lights were

mostly already embedded in the living room infrastructure. For more remote locations an infrared network was designed. This was constructed using a powerful master IR transmitter, which, by means of a large array of IR photodiodes was able to transmit and receive from longer distances than standard IrDA transceivers. Remote devices were equipped with transceivers (slaves), and adhered to a synchronous serial protocol as described in Chapter 7.

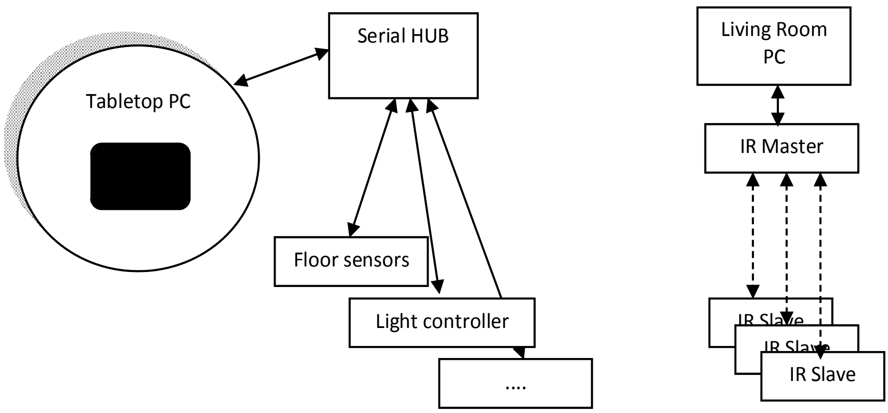

Figure 5.6 Living Room network infrastructure.

Tests with the IR network showed that the transmission power of the IR array was more than sufficient, but the smaller slave devices (with less powerful transmitters) had difficulty in transmitting their responses to the server. Furthermore, transmission from the master was strong enough to bounce off walls and penetrate thin transparent material but the response from the slave was easily lost if there was no direct line of sight to the master. The next logical step was to move to RF transceivers, which at the time were becoming increasingly popular due to lower prices and highly integrated modules. The synchronous serial link was also discarded in favour of standard RS-232 transmission, either over RF or cable. The RF link acted like as a serial cable, so that changing to a physical cable or a RF card was possible without modification to the devices themselves. The RF link had a range sufficient to cover the apartment, and the matchbox-size transceiver was easier to install than the cumbersome IR links. The RF link is described below in greater detail.

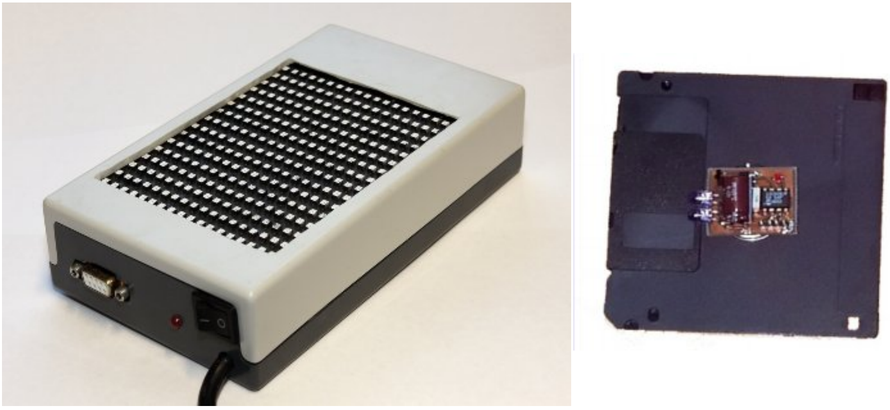

Figure 5.7 IR master array used for wireless communication (left), IR slave device (right).

With standard RS-232 communication becoming the used standard in the Living Room a problem arose with the limited availability of serial ports on the server. In order to connect several devices into one serial port on the PC, it was decided to construct a serial hub. A four-port hub was considered sufficient, and allowed four devices to share the same serial port to the PC. Since the network was designed as a master/slave type there was no danger of collisions or lost packets because the master always initiates communication.

5.2.2 Living Room User Interface

The primary UI for the Living Room was the tabletop-PC mentioned above. The PC was constructed from PC/104 - compliant [PC104] modules (i.e. a “biscuit PC”), embedded inside a round table and equipped with a touch screen and batteries for mobility. This way the PC was basically a mobile UI that could be moved to other parts of the room if needed. Batteries provided an operating time of about two hours. The main graphical UI of the Living Room included a master status page, separate lighting control, home A/V equipment and house plant monitoring pages. The UI allowed users to monitor conditions in the home and also make adjustments and control equipment. In addition, there were pre-set modes for watching TV or listening to music. Controls for A/V equipment allowed users to discard traditional infrared remote controls and control all equipment from a single location.

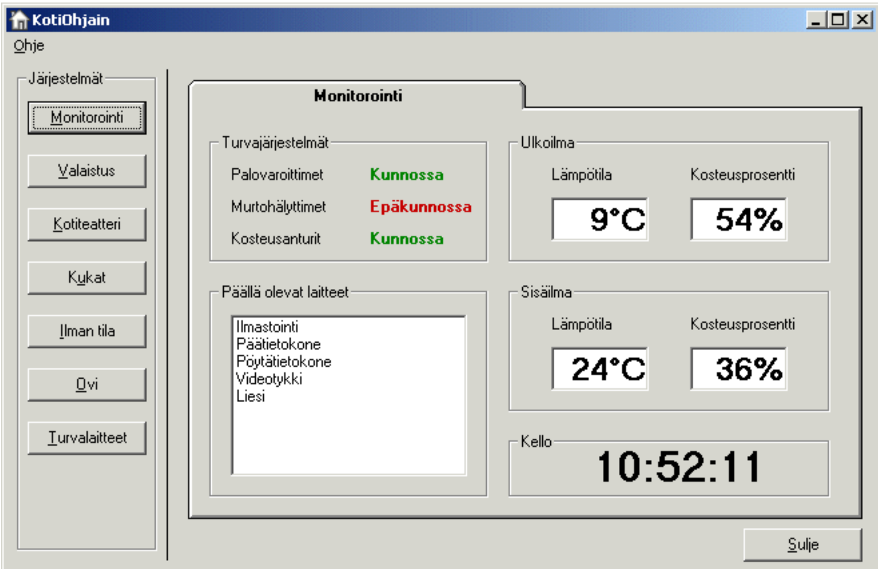

Figure 5.8 Main screen of the Living Room UI. To the left are quick buttons for accessing lighting, air quality, home theatre etc. The main page shows temperatures and device information.

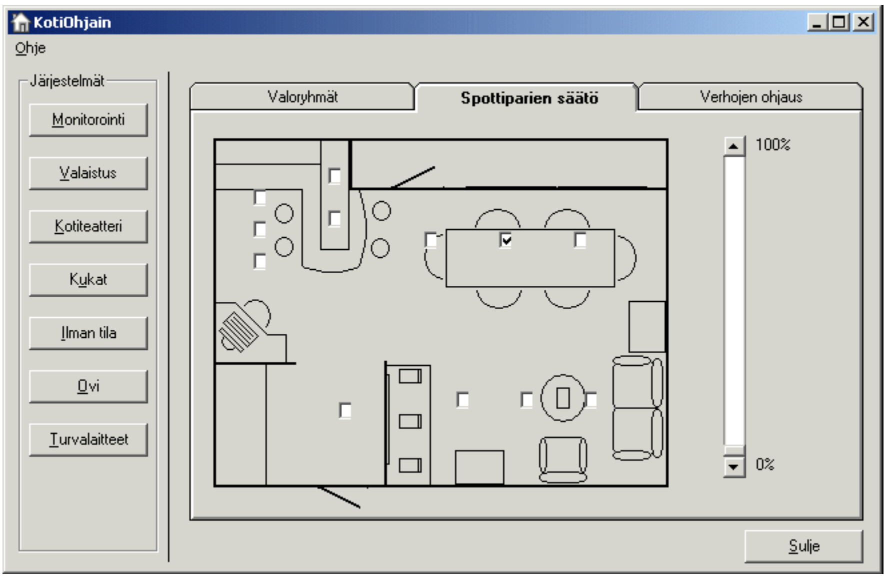

Figure 5.9 Lighting control screen. Individual spots can be selected from the image, and brightness adjusted from the slider.

Figure 5.10 Home theatre controls, with mode selection buttons.

5.2.3 Controllable Devices in the Living Room

Flower Pot

The first device constructed for the Living Room was a flower pot monitor. Here it was decided not to implement automation since an aspect of a pleasant environment is active participation. The user would take care of the plants though there was a backup system to activate reminders should the user forget. The flower pot monitor was designed to monitor the health of the plant by measuring the water level in the tank beneath the flower pot with two strips of wire measuring the resistance between them. The purpose was to alert the user if the flower became dry or had too much water. Depending on the potted plant, a suitable schedule and profile could be used to ensure optimum health and growth. Users could monitor the plant's condition and measurement graphs from the graphical UI running on the PC.

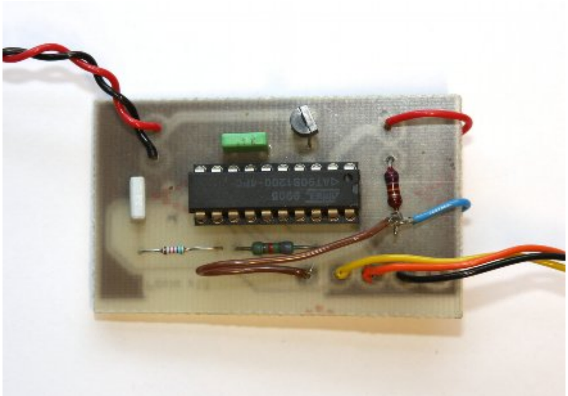

Figure 5.11 Flower pot sensor.

Motorised Curtain

The artificial balcony in the Living Room had a large window with two bright lights behind to simulate daylight. The artificial sun “rose” in the morning becoming gradually lighter and “set” again in the afternoon. The quality and amount of ambient light makes users subconsciously aware of the time of day and can also be used to set a suitable atmosphere in the apartment. A motorised curtain was installed to control the amount of light entering the room. The curtain motor was connected to a controller card, which was controllable from the tabletop PC.

Infrared Tags

Identifying the user is a primary requirement for personalisation and customisation in smart environments. When the user is identified the information can be used for access control, personal greetings etc. In the Living Room coin-sized infrared tags were used for identifying users. The tag was battery powered and transmitted an ID code every few seconds. A pin allowed users to wear the tag like a badge. A tag reader mounted near the front door was able to read the infrared signature transmitted by the users tags. If the ID received matched the list of known users the tag reader would unlock the door. Another application for the tags was a wine bottle rack that identified the users accessing it. Unauthorised use of the rack would register an alarm on the server, displaying the person’s identity or in the case of an unknown person, the time and date of the theft.

The system was originally designed to work in the opposite way, with a person carrying the tag reader and tags being placed onto objects of importance around the home [Häkkinen00]. However, since the reader was physically considerably larger than the small-sized tags, it was considered easier to make the tags mobile and place readers in appropriate locations in the Living Room.

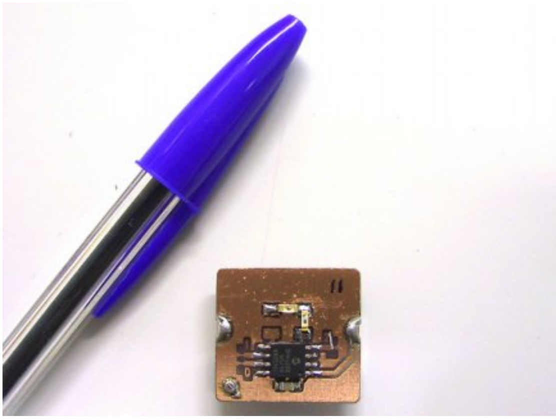

Figure 5.12 Infrared tag (left), tag integrated into a brooch (right).

Front Door

The front door was equipped with an electrically controllable lock. An infrared transmitter/receiver pair was installed in the door handle to sense when a person was clasping it (in order to open the door). An infrared reader mounted on the outside wall read the persons IR tag, and if the person was recognised the lock would open. The door monitor was not connected to the home infrastructure, but was a stand-alone device programmed to respond to certain IR tag ID numbers. At a later stage, the infrared detector in the handle was changed to a capacitive sensor that reacted when a person was touching the handle. This enabled faster and more reliable sensing, and it removed the need for the person entering to touch the handle in a specific way (i.e. putting the hand completely around the handle in order to block the IR receiver/transmitter pair).

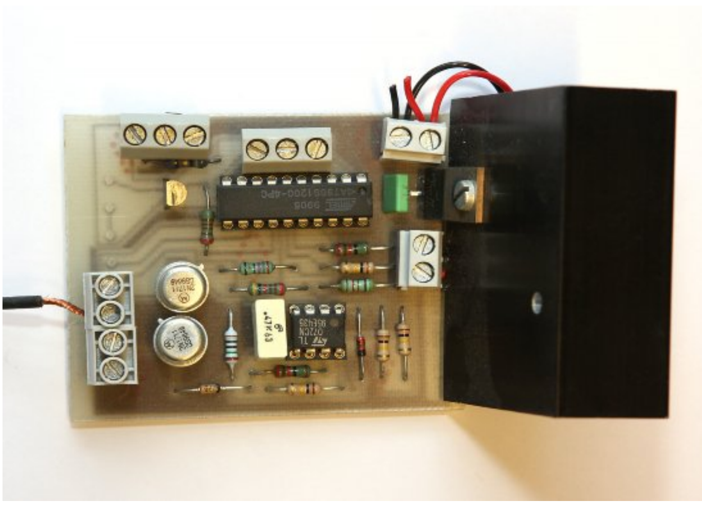

Figure 5.13 Door opening unit with control for the electrical lock.

Halogen Lights

Lighting in the Living Room was implemented using ceiling-mounted halogen lights. All lights were controlled by the computer with a special controller card, which also enabled stepless dimming. Each light could also be controlled separately, making it possible to adjust brightness in different parts of the room. The controller also allowed lights to be grouped according to their physical location, as well as enabling manual control from traditional wall-mounted switches. The dimming feature and control of individual lights enabled users to set different moods and also control the lighting of the space in a precise manner. Lights could also be controlled using various sensor data, for example according to movement data from the floor sensors. The lights were controlled primarily from the tabletop PC using a graphical UI but manual light controls were also implemented.

The light controller was constructed using a microcontroller and low-resistance MOSFETs. The dimming function operated by switching the MOSFETs on/off with a high frequency (pulse width modulation) using 12 V power from a massive toroid transformer.

Figure 5.14 Halogen lights and controlling unit.

Sofa Sensor

The entertainment area of the Living Room was equipped with a two-seater sofa and a recliner. People were often seated on the sofa when watching a movie and so that placing sensors in the sofa would provide information about them. The primary application for the sofa sensors was context detection regarding the home entertainment equipment. Thus, for example, if a movie was playing and the viewers got up from the sofa to get a drink from the refrigerator the movie would pause automatically. Sensing was achieved by means of stretch slip sensors installed inside the sofa cushions and a controller unit that sent on/off data to the computer. The sofa was designed for two people, and it was possible to detect which seat was occupied.

Floor Sensors

Locating users in the Living Room was a primary requirement for the infrastructure as it allowed the system to determine the location and activities of the users. This information could be used for lighting control, access control and for contextual applications. Sensing was achieved with special EMFi sensors installed in specific parts of the apartment. [EMFi] EMFi is a sensor film material that converts mechanical pressure into proportional electrical energy and vice versa. Mechanically it is constructed of thin air-isolated polymer layers acting as charged plates of a plate capacitor. Due to the relatively high cost of the sensor film material it was not possible to cover the entire floor area with sensors and, as a result sensor film was installed at locations where people would be most likely to walk when moving from one room to another. Though the integrated EMFi-film amplifier gives both analogue and digital outputs, the latter was used to obtain *present/not present* type information from the sensors. One problem with EMFi-film was, however, that it only responded to state changes. The effect of this was that when a person stepped onto a sensor pad the sensor gave a reading, but when the person remained standing on the pad it ceased to register anything more. Only once the person had stepped off could another reading be obtained. This made the sensor useful for movement, but unsuitable for measuring static conditions.

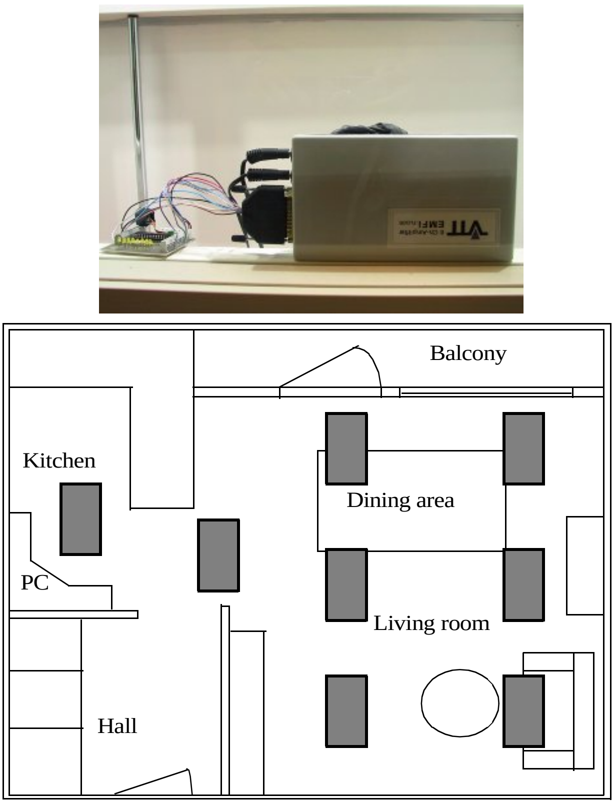

Figure 5.15 EMFi sensor board and control unit (top), approximate placement of EMFi sensors (bottom).

Odour sensor

A sensor measuring air quality, odour levels, air pressure, nitrous oxide and carbon dioxide content was installed to monitor the well-being of the occupants. Commercially available sensor modules made it possible to construct an integrated sensor unit capable of measuring above-mentioned quantities. The quality of the air inside the home can affect users in various ways, both physically and mentally. Ventilation in rooms is often inadequate and wastes energy, and knowing when and where ventilation is needed can considerably improve the situation. In larger cities with variable or poor air quality, measurements could also be taken outside to determine if it is safe to open the windows or turn on the ventilation.

The sensor unit used in the Living Room was a module that contained numerous types of sensors, each with their own measurement method. The air quality sensor was sensitive to abstract characteristics such as cigarette smoke, coffee, cosmetics and cooking. Although the odour sensor did not provide a definitive reading on the air quality in the Living Room, it could still be used for detecting a need for ventilation. Indirectly, combined with readings from the integrated carbon dioxide and nitrous oxide sensors, it also indicated when the room was occupied by several people or if certain activities were taking place.

Figure 5.16 Odour sensor unit.

IRemote

Home entertainment and A/V devices rely on optical infrared transmission for remote control, and in order to control them a universal remote control was needed. Since homes already contain several devices that require infrared remote controls, there are often a plethora of bulky remotes. Additionally, each remote has a different layout, buttons and functions making the task of turning on all equipment and setting them up rather tedious. To combat this problem an infrared network node was constructed. The node, named “IRemote”, was connected to the serial network, received commands from the master PC and

transmitted them to A/V devices over an infrared link. This made it possible to control the DVD player, video projector, etc. without having to use legacy handheld remote controls. The IRemote node was pre-programmed to incorporate all the remote functions for each individual device.

In addition to the IRemote another control method for A/V equipment was tested. CASIO had produced a wrist watch (model CMD30B-1A) with an infrared transmitter and built-in control buttons. Essentially, this was a wearable programmable universal remote control. The watch was able to command individual devices directly using programmable buttons on both sides. When buttons on the watch were being operated, the watch would send an infrared signal to the IRemote unit, which in turn would perform the appropriate tasks with the A/V equipment.

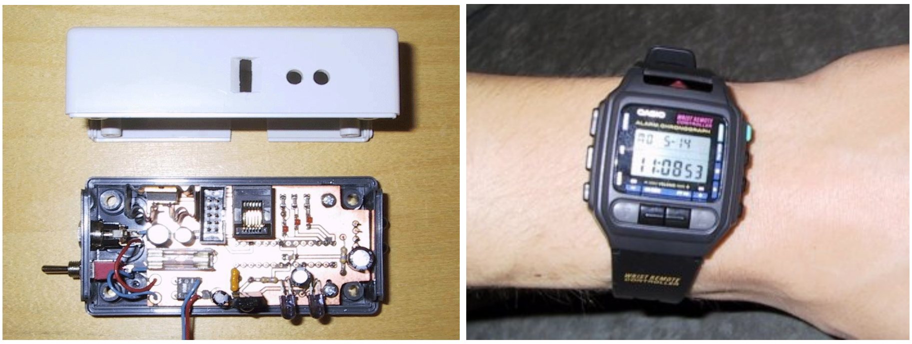

Figure 5.17 IRemote unit and CASIO IR wrist watch.

5.3 The Smart Home (2002->)

Two years after the Living Room project started the Department of Electronics moved to a new building in the university. Plans included a dedicated 69 m^2 laboratory space for smart home research.

Figure 5.18 The Smart Home laboratory.

There was now an opportunity to conduct smart home research in a complete apartment with kitchen, bedroom, living room, bathroom and sauna. Furthermore it was now possible to design the apartment from scratch with prototyping and testing in mind. The laboratory space was named the “Smart Home” and furnished to resemble a typical modern apartment. However, many changes were made to the structure and design to allow easier modification and installation of new systems and appliances in the future. A suspended ceiling houses bright controllable halogen lights, electric sockets, network sockets and generous room for equipment, while the raised floor contains electric cables and additional space for floor sensors. Rooms are separated by large movable shelves to allow changes to the room layout. The shelves also have hollow ducts and space for cabling, concealing cables and making later installations easy. The biggest modifications were made to the electrical network, which eventually contained several kilometres of cables. This was due to our requirement that every light and electrical socket should be directly controllable with relays. The main electric distribution board houses all the necessary relays and switches, and thus it became significantly larger and more complex than usual. This would, however, allow flexible control of all electrics in the apartment, turn off devices as needed and form logical groups.

Figure 5.19 Bedroom, Bathroom/Sauna and kitchen in the Smart Home.

The network infrastructure was imported from the Living Room with some features being redesigned for the Smart Home, but both RS-232 and RF networks were retained as the primary network types. The only devices that were directly used from the Living Room were the IRemote and halogen dimmer. The tabletop PC was replaced with a new central computer, a shoebox-sized Shuttle XPC, which was installed in the bedroom.

The Living Room was devised for conducting further studies on user interfaces, home networks and other smart home technology. One key research item was network and device interoperability; how could incompatible devices from different manufacturers be interconnected and used through the same home network? Thus the goal of this research evolved into proving that with appropriate system architecture, it is possible to connect devices from different manufacturers to a common infrastructure. Creating a home network either requires the re-design of all devices or the creation of network converters, and the Smart Home laboratory experiments with both ideas. An affordable or cheap solution to the home networking problem was sought by implementing a complete home network with various user interfaces and conducting long-term tests. Existing and proven network standards were used as widely as possible and adopted in the Smart Home [Kaila05_2].

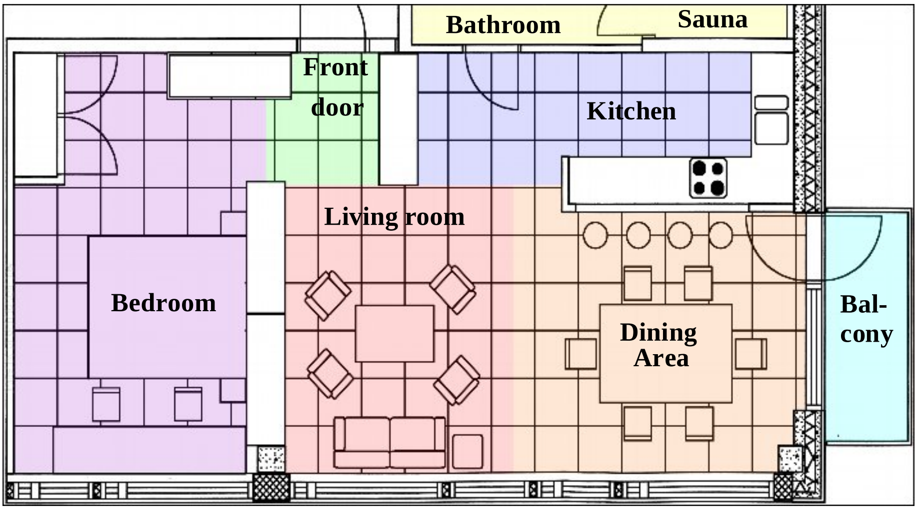

Figure 5.20 The Smart Home laboratory, showing rooms and furniture.

Sensors (temperature, humidity)

Small, deployable temperature/humidity sensor modules were installed around the Smart Home, making this the first test with sensor networks in the Smart Home. These sensors can help the system by analysing conditions both inside and outside the home. The sensor module contains separate probes for temperature and humidity measurements, both connected to the module by a short cable. The module can use either wired or wireless network connections. In the Smart Home, modules are installed in the living room, sauna, flower pot, refrigerator and on the outside. Other devices can also contain temperature sensors and their measurement data can be used to augment readings from standard sensors. An improved version of the flower pot monitor was also constructed. The new version featured the former water level sensor and additional humidity, temperature and light sensors for even more precise monitoring of the potted plant. In order to have better control of the amount of light the plant would receive, an external dimmer module was also incorporated to enable control of an external flower light.

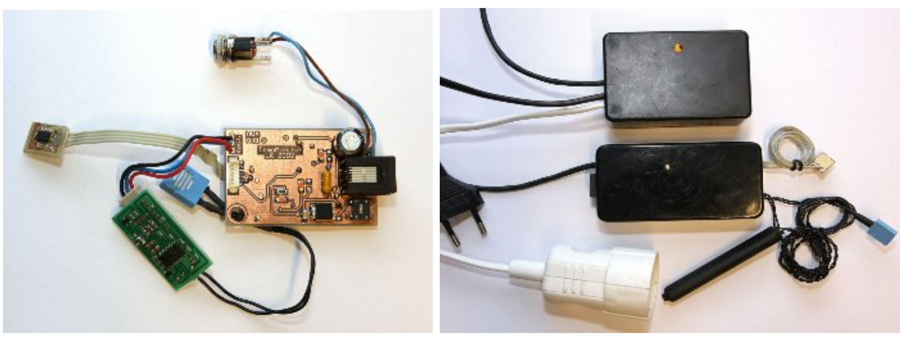

Figure 5.21 Living Room sensor module with temperature and humidity sensors (left), improved flower pot sensor module (right).

Motorised Blinds, Screen and Curtains

Light sources inside the apartment can be used when it is dark outside, but otherwise there is a need for some form of control over the amount of ambient light entering the rooms. Light level management might sound simple in theory but in practice there are numerous variables that affect the way we perceive light in the home. Thus it is important to have many ways of creating or removing light, either naturally or artificially. With a proper control system it is also possible to save energy because lights left on during the day or when nobody is present waste energy. The burden on the user is reduced and the cost and energy consumption of the controlling system can quickly return the investment.

All windows in the Smart Home are equipped with motorised window blinds and curtains that can be controlled and adjusted to a desired position. Blinds can be used for precisely the precise amount of ambient light entering the room while curtains can be used to block all light which can be useful when watching TV, for example. There are projection screens in the dining, living room and bedroom that can be used for entertainment or meetings. In the bedroom these can be used to show restful images to create a relaxing environment. The screen in the living room is intended to be the primary screen for the home theatre, and a large video projector is mounted on the ceiling for this purpose. The main screen is also equipped with a controllable motor.

All of these devices are based on commercially available products, but the supplied standard control units have been replaced with custom controllers that are connectable to the Smart Home network. The window blinds can thus be controlled to any position, and the rooms can be completely darkened if needed. The projection screen in the living room can be set to lower at the when the projector is turned on.

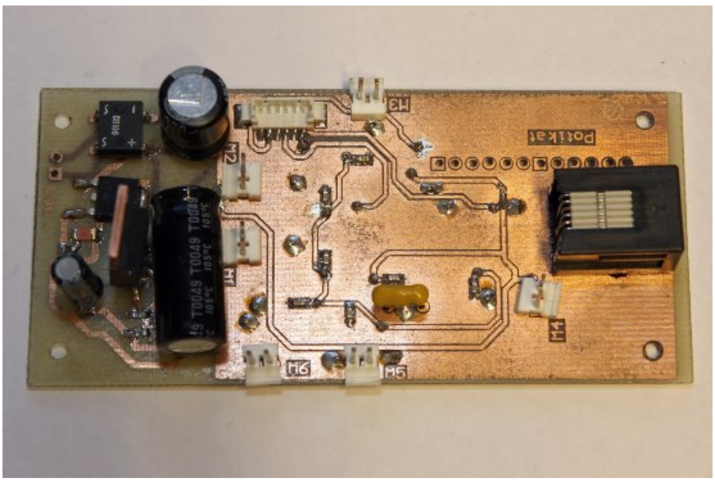

Figure 5.22 Control unit for motorised blinds.

LINET Network

The requirement to control all the lights and electric sockets in the apartment caused a need for a dependable control network. As it was considered difficult and possibly hazardous to custom design the control of mains voltages, it was decided to acquire a commercially available product. LINET [LINET] is a proven product that suited our requirements, and since it was also possible to interface the LINET control unit with our Smart Home infrastructure, it was seen as a logical choice. LINET enables switching and dimming controls for lights; it controls relays and allows for grouping of its network nodes. In this way it is possible to individually turn on or off a light or mains socket, or to create a controllable group that responds to the press of a button. In the Smart Home a push button near the front door is configured to turn on/off all lights in the apartment, making it easy to ensure that all lights are turned off when leaving the apartment. The LINET network comprises of one network master unit and multiple slave nodes and it uses a time-division multiplexed protocol and twisted-pair cabling, supporting up to 255 network nodes. Electric power to the nodes is also supplied by the same wires, making cabling relatively simple even in older buildings. The LINET master uses an Ethernet connection to connect to the Smart Home network, enabling control of the network from another user interface as well. The status of lights and relays can also be read, which is a major advantage when displaying items on a graphical UI. Each controllable relay, dimmer and light switch on the wall contains a LINET node that can be reprogrammed to perform any function that the protocol supports.

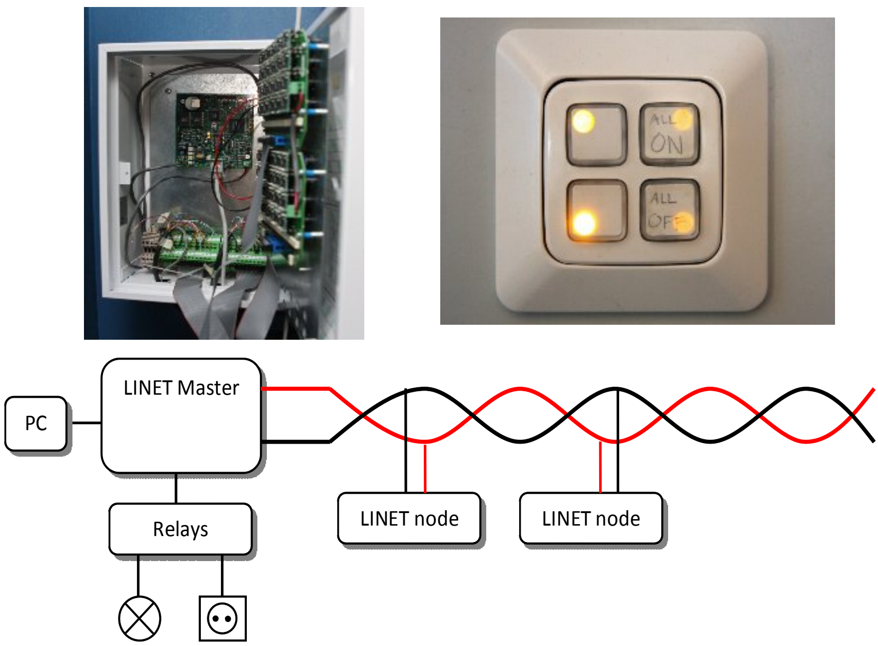

Figure 5.23 LINET master unit (top left), light switches (top right) and network connections in the Living Room (bottom).

Motorised Door and Fingerprint Scanner

Experiments with the motorised lock and ID tag reader in the Living Room revealed that alternative methods for implementing access control were interesting, and the concept was developed to include a fingerprint scanner and motorised door. The front door to the Smart Home was thus motorised and fitted with an electric lock. The door could be opened in the conventional manner with a key or from the inside by pressing a button. A door controller unit was also constructed to allow the door to be opened remotely through the home network and a USB fingerprint scanner was installed to control access to the room. The scanner, which is physically located next to the front door (on the outside), is connected to a PC in the Smart Home, which runs fingerprint scanner software. The database contains fingerprints of all persons that are authorised to access to the room, and once a positive match is made the software sends a signal to the server software to open the door. The fingerprint software also sends out a text string containing the person's name, which the server outputs to the speaker outside the door. The individual person can then hear a personalised welcome message on entering the room, such as "Welcome Lasse, it's a nice day today!".

Figure 5.24 Fingerprint scanner near the front door of the Smart Home.

Controllable Lights

Lighting was constructed using halogen spots in a similar way to the Living Room. The Smart Home is equipped with 45 bright 50 Watt halogen lights that can be individually controlled. Currently, however, the lights are grouped according to the rooms they are in, making it easier to control lighting at room level. Apart from those in the living room, all lights in the Smart Home are controlled through the LINET network, with pushbuttons in the wall controlling corresponding light groups. However, as an exception halogen lights in the living room are controlled using the dimmer module from the Living Room project. Light groups are as follows: Sauna, bathroom, kitchen, kitchen desk, dining room, living room, hallway, balcony and bedroom.

Speech Control and Audio Feedback System

Speech control allows users in the Smart Home to give voice commands to the system and thus removes the need of buttons, screens and other physical UIs. With PCs having enough processing power to recognise words and sentences and the availability of speech recognition software, this presented an interesting option. SCARS (Speech Control and Audio Response System) is an experimental user interface, which uses speech as input and computer-generated audio as output [Hyvönen03, Kaila09]. A portable wireless microphone is used to give speech commands to the server, and the system can provide audio feedback to the user from ceiling-mounted speakers. The microphone is also equipped with a locator, so the system knows where the person is using the microphone, making it possible to direct audio and audio feedback directly to the user. Another advantage is context awareness: issuing commands in the living room would control devices in the living room. For example, if the user walked into the living room and commanded “lights on” the system would turn on the living room lights. Positioning is achieved with infrared transmitters placed in the ceiling all around the apartment, and a receiver set in the microphone unit. The Smart Home laboratory is divided into six separate areas (rooms), each having its own speaker, location ID and set of controllable devices.

The microphone has a push button that the user presses and holds when issuing a command. A beep is heard from a nearby speaker, after which the system is ready to accept a voice command. After the command has been received the system can take appropriate action and play a confirmation message from a speaker near the user. Using a dedicated talk-button eliminates the need for constant listening and makes it easier for the computer to capture the command. Speech recognition is performed on the Smart Home server, which runs speech recognition software. A text-to-speech converter is also used for giving audio feedback to the speakers; the software also makes it possible to send any text string to be read aloud to the speakers. In order to minimise faulty recognition and speed up recognition time the software is set to recognise only a certain set of commands. This allows the microphone to be used by others and not only the person who has recorded the original commands to the software.

An example of the dialogue between the user and SCARS could be a case where the user controls the lights in the living room. The user commands “living room lights on”, to which the computer responds “living room lights turned on” and takes the appropriate action (in reality, both commands and audio feedback are in Finnish).

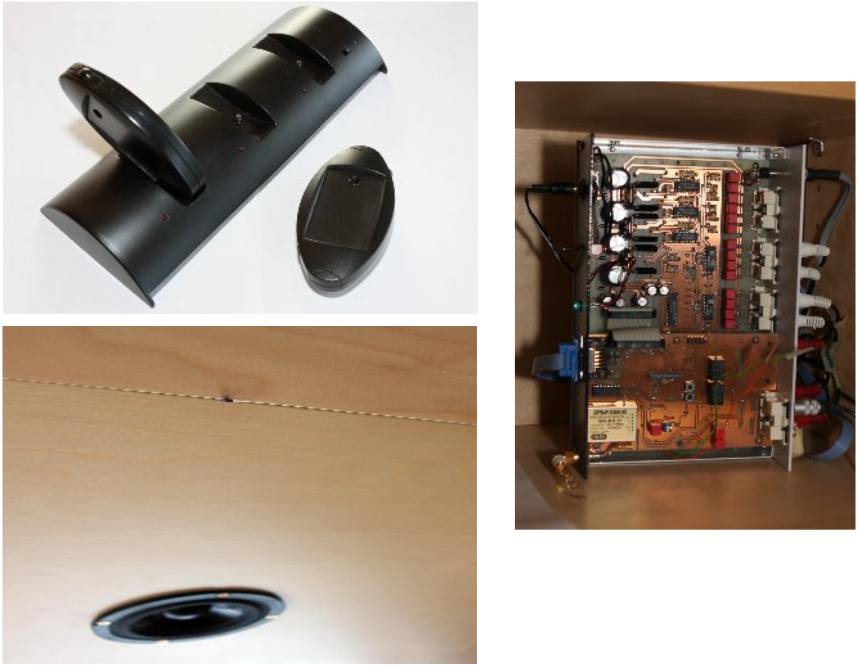

Figure 5.25 SCARS microphones and charging station (top left), ceiling-mounted speaker and infrared diodes (bottom left) and receiver unit (right) [Hyvönen03].

Location Sensors

As with other sensors, the floor sensors in the Living Room proved that this kind of information is highly relevant to smart home applications. Since the Smart Home had removable floor tiles it was possible to test different ways of measuring movements and presence in the apartment. The sensors used in the Living Room test apartment were EMFi film sensors, but using these throughout the Smart Home would have been extremely expensive. Thus alternatives were sought, and first test were made with strain gauges, one placed beneath each corner of a floor tile. Strain gauges are conductors whose resistance changes as their physical dimensions change (e.g. when they are stretched). These sensors were able to detect when a person was stepping onto a tile, but covering the whole apartment with strain gauge sensors would have been a major undertaking involving a lot of wiring and sensors [Koskinen03]. Other alternatives for locating people were passive infrared sensors (PIR), which detect the movement of people. Such a sensor is in use in the living room area and detects if people are seated around the living room table. For accurate user tracking, however, they are unsuitable and too inaccurate.

Experiments have recently been conducted with capacitive sensing by utilising the metallic sheets inside the Smart Home floor tiles. By using a wire as a receiver and tiles as transmitters it is possible to detect changes in capacitance when people are walking on the tiles [Valtonen09]. A single tile is 60 x 60 cm in size, and if the metal sheet beneath it is cut into

even smaller pieces greater accuracy can be obtained. Problems are caused by differences in footwear (is the person wearing shoes or not) and carpets, both degrading the sensing capabilities. However, the floor tile approach would yield a reasonable accuracy and could be used throughout the apartment without the need for much additional infrastructure.

Figure 5.26 Smart Home PIR sensor (left), floor tiles in the Smart Home (right).

5.3.1 Smart Home Network Infrastructure

Figure 5.26 below shows different networks and their connections in the Smart Home laboratory:

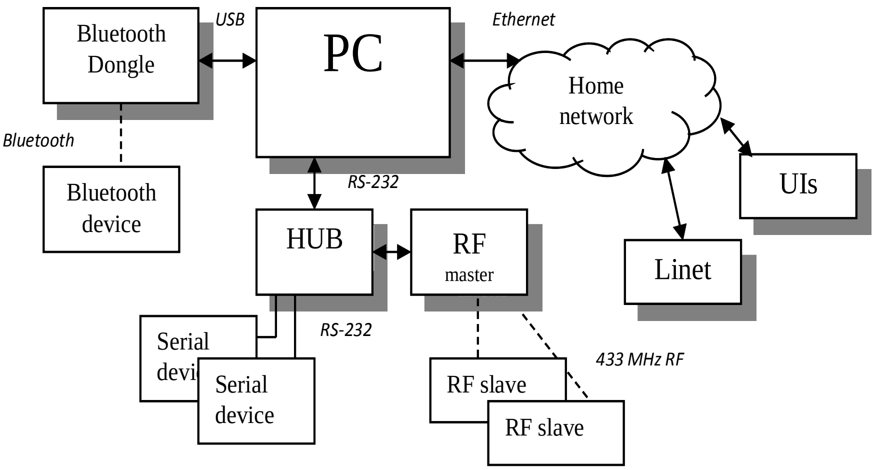

Figure 5.27 Network infrastructure of the Smart Home.

The Smart Home contains numerous networks, each with its own purpose and design [Kaila07]. The primary network is the RS-232 network, to which most sensors and actuators are connected. Serial port devices communicate at 19200 bps which is more than enough for the few bytes that sensor data and commands require. The wired serial link is designed to be used wherever the infrastructure permits cables and where robustness and dependability is important. Because RS-232 is a point-to-point communication method a way to connect multiple devices to a PC was required and work on a serial network hub was also needed. Since the network was a master-slave type it was possible to construct a hub that would allow multiple serial ports to be connected to a single port, as was done in the Living Room. The new serial hub houses 14 serial ports with RJ-12 connectors that can be directly connected to compatible devices in the Living Room. One serial port is dedicated for connection to the server PC, and one port is reserved for wireless connections. Addressing is done by assigning a unique address to every port, and the device automatically gets the address according to the port it is plugged into. The devices themselves have no record of their address, the server software keeps a record of all addresses, and the serial hub merely ensures that messages are delivered to and from the correct port. For wireless RF devices, a unique ID number has been programmed into the wireless transceiver modules, and this address is used in a similar way as with wired devices.

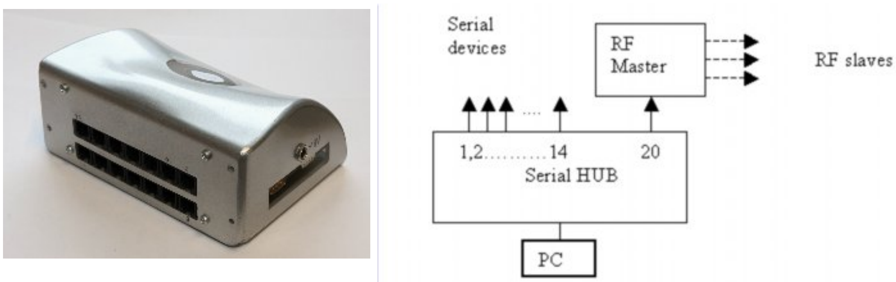

Figure 5.28 RS-232 network hub used in the Smart Home. Wired devices have addresses 1...14, wireless devices from 20 onwards.

When the server needs to send a command to a device, it opens the communications port to the hub, transmits a command and device address and waits for a reply. The hub redirects this command to the appropriate port, waits for a reply and relays this data back to the PC. This solution makes it impossible for a slave device to open a connection to the server, instead all connection attempts have to be opened from the server side.

The wireless alternative to the wired serial network uses matchbox-sized transceiver modules and a master unit to replace cumbersome serial cables. Wireless RF is used whenever cabling is too difficult to implement, the distance too great or if greater flexibility or mobility is required. The wireless transceiver module plugs directly into the serial port of any smart home device and connects to the Smart Home network via the master module. The transceiver consists of an RF board with a single-chip transceiver and PCB antenna and a microcontroller board with external interfaces. The nRF401 radio module has sufficient range to cover the apartment without the need for external antennas. The transmitted RF

power of the module is about 10 dBm, which permits a range of 20 m in a normal living environment and the maximum data rate of the module is 20 kbits/s.

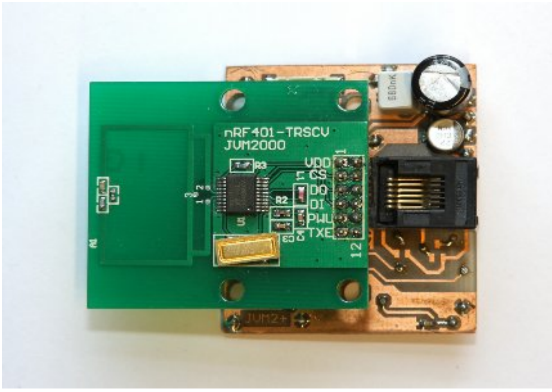

Figure 5.29 Smart Home RF module [Mikkonen06].

Bluetooth devices are connected in a similar way, using a proprietary Bluetooth module. The module houses a Samsung BTMZ5012A0 single-chip transceiver and an interface for initiating a pairing sequence or re-connection. The module has to be paired with the Bluetooth dongle in the server, after which it opens a virtual serial port connection between the two. Thus the Bluetooth connection also appears as a standard serial port to the server. The Bluetooth module consists of a Samsung class 1 integrated transceiver module, RJ-12 connector, buttons for pairing and connecting and indicator LEDs.

Figure 5.30 Smart Home Bluetooth module [Myllymäki03].

An alternative to wired RS-232 communications is Ethernet, and a module for converting the RS-12 connector specification used in the Smart Home to standard Ethernet UDP communication was also made [Mäkinen03]. This made it possible to communicate over larger distances and other networks.

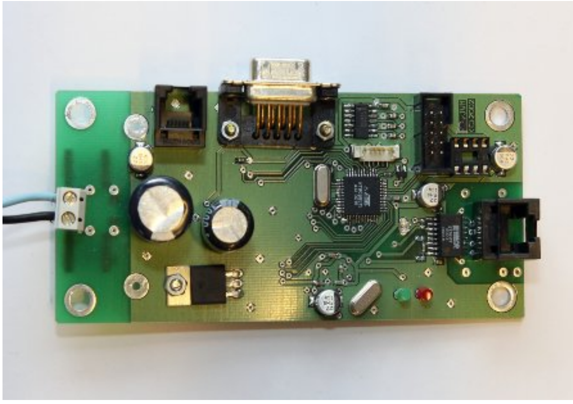

Figure 5.31 Smart Home Ethernet module with RJ-45 and RJ-12 connectors [Mäkinen03].

5.3.2 Smart Home User Interfaces

Smart Home user interfaces were designed to be totally different from the prototype UI in the Living Room. A touch screen was still considered to be the most intuitive method of controlling the main graphical UI, but additional ways of interacting with the home were also deemed necessary. If all functionality is invested in a single UI there might be situations where the UI is in the wrong place or users simply fail to pick it up and make adjustments. For this purpose we designed mobile UIs, one for a mobile phone and one for wireless speech control.

The primary Smart Home UI is a touch screen - equipped tablet PC. Being a tablet PC it is easily carried around the home to wherever needed. The tablet runs a graphical Java program, the “Home Controller”, which allows the users to control and monitor equipment in the home. The main page gives an overview of important temperatures, shows which lights are turned on and allows adjustment of lights, blinds, curtains and the front door. Another page is dedicated to home entertainment, such as “Watch a DVD” and “listen to music” macros that allow users to input a preset mode at the press of a single button. For example, by pressing the “Watch a DVD” button the DVD player, amplifier and projector will turn on and be set in appropriate modes, window blinds and curtains will close, living room lights will dim and the projector screen will lower. Other preset modes allow users to turn off the equipment and resume normal daily routines etc. The same page also includes controls for A/V equipment, as in the Living Room. The DVD player, VCR and surround amplifier can be controlled from the same pages, making infrared remotes unnecessary. The tablet uses a TCP/IP connection over WLAN to the server.

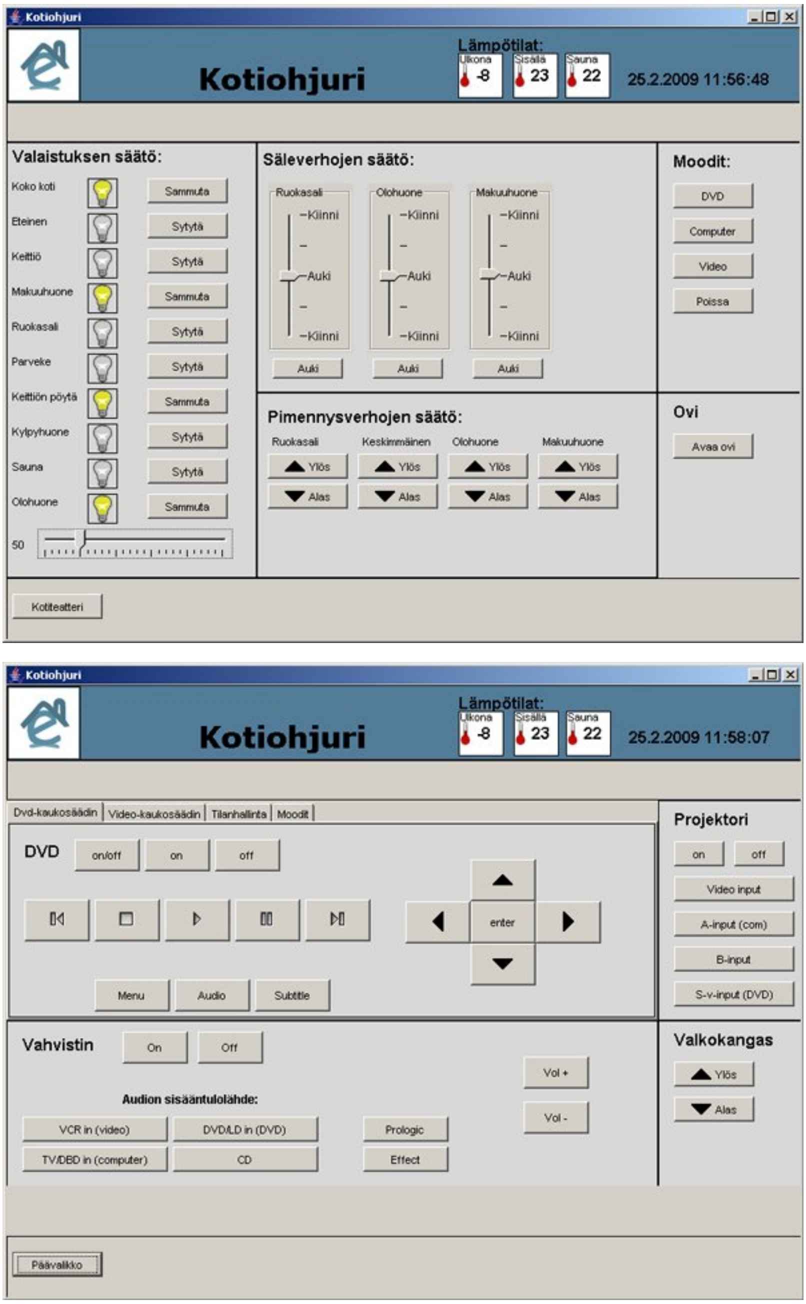

Figure 5.32 Screenshots of the Smart Home tablet UI. Top: main page showing lighting and curtain controls, temperatures and quick selection buttons. Bottom: A/V page showing controls for the DVD player, projector and amplifier.

In 2002 mobile phones were becoming increasingly versatile, they came with large displays and it was also possible to install and write sophisticated software for them. A miniaturised version of the tablet UI was written for a Series 60 [S60] - based mobile phone, a Nokia 3650. The Symbian operating system and Series 60 user interface made it possible to write a customised UI for the phone and use the phone's Bluetooth interface for communication [Ritala03_1]. The phone UI is designed for use with the multi-directional controller on the phone, and when a selection is made the phone communicates with the server and the corresponding action is taken. The phone UI allows users to monitor temperatures, control lights, blinds, curtains, and the front door.

Figure 5.33 Smart Home mobile phone UI.

Wall Panel UI

While the concept of the disappearing computer [Schenker00] did not mean its actual physical disappearance the concept was nevertheless quickly directed towards user interfaces [Dey01_2]. This prompted speculation as to whether walls, panels and surfaces of equipment could be kept aesthetically clean and their UIs made invisible, only to appear when needed? A disappearing UI would normally pose no problem for users, but if it was needed for any reason or if there was something that required the attention of the users, it would readily become available.

Experiments with LED lights and thin veneer were very promising, as they proved that it was possible to create a wood-like surface thin enough for light to pass through. This gave rise to the idea about creating a transparent display with a wooden surface. The goal was to devise a user interface which would normally be invisible until a person walked by or waved a hand in front, when the panel UI would come to life and be visible. A prototype with four pushbuttons and a light dimmer control was designed using thin veneer and chip-

board and embedded in one end of a cabinet in the Smart Home. The buttons consist of LED patterns which light up, and the light dimmer is a slider which allows users to control brightness in discrete steps. Controls include all lights on/off, dining area lights, bedroom lights, kitchen lights and living room lights (dimmable). All controls are touch-sensitive, buttons operate by touch and the slider by touching and sliding a finger on the scale. If the panel is out of use for approximately ten seconds it turns itself off. A capacitive touch sensor performs touch recognition and a small speaker beeps when adjustments are made. The panel is connected to the home network using Ethernet, and serves as an alternative to wall-mounted pushbuttons. An alternative design was also created, being similar in function but the button layout was redesigned to display the floor plan of the apartment instead. By touching the appropriate room the light controls for that room can be controlled, and a slider for the dimmable living room lights is also present. A further updated version of the panel UI is currently being designed, with more intuitive graphics and functions. The ultimate goal is to make the electronics thin enough so that they can be embedded in a thin film or inside the actual building material (plastic, wood, textiles etc.).

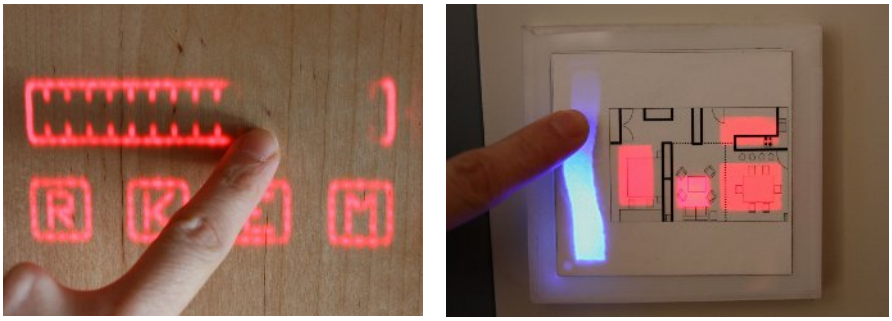

Figure 5.34 Smart Home wall panel UI prototypes, one embedded into the end of a cabinet (left) and a newer version located next to the front door [Raula09].

Home Server

The centre node of the Smart Home network is the server PC. This is basically a standard miniature-sized PC running Windows 2000 and is connected to all devices and sensors in the home environment using various network and connection types. Currently RS-232 (using COM ports 1 and 2), Ethernet (both TCP/IP and UDP) and Bluetooth are currently being used. Wireless connections, such as proprietary RF and Bluetooth actually appear to the Home Controller as serial ports; the RF link (through the serial hub) is connected via the serial hub and Bluetooth devices (using a standard USB-dongle) use the standard serial port profile and are mapped as virtual COM ports on the PC.

Figure 5.35 Smart Home server in the bedroom.

Home Controller Middleware

If the server PC is the centre of the network then the heart of the Smart Home is the server software that connects to all devices and user interfaces [Vainio06]. The Home Controller is a Java-based centralised middleware software designed to contain multiple different control interfaces. From the outset, the Home Controller was designed to be modular to make it easier to add more functionality, while the infrastructure-style approach [Hong01] makes it versatile and platform-independent. Over the years new networks, protocols and functions have been added, and this modularity has proven very valuable for the Smart Home's changing research environment. Currently the Home Controller uses LINET, TCP/IP, UDP, new Smart Home protocol and Smart Home UI protocols (described in Chapter 7).

Physical devices are modelled in the server using XML-based descriptions. The description contains a brief outline of the device and its functions, a list of commands and values that the device uses and understands, information on the protocol and network type that the device uses, device address (where applicable), polling interval and possible scaling or other data format options. The following is an example an XML description of a temperature sensor (which gives its output as two's complement, in °C):

```
<device name="OutTemperature" protocol="rf" connection="com" addr="04">
<function id="31" name="OutTemperature" idgroup="sensors" get="01" pol-
lint="60000" unit="°C">
<description short="Outdoor temperature">
    Temperature outside the building
</description>
<return format="01vvxx"/>
<valuerange lowerlimit="-128" upperlimit="127" scaletype="2compl"/>
</function>
</device>
```

The Home Controller software creates generic Java-objects based on these descriptions. When each object is aware of the protocol and the network it is using for communicating with the physical device the networks and protocols that the devices actually use become irrelevant to the server. An XML-parser module reads this information and creates corresponding objects for the server software, concealing the physical networks behind an abstract interface. If a new network or protocol is introduced all that is required is a physical connection to the server PC and a driver or a handler for the protocol. When the XML description is updated the device is ready for use.

The Home Controller can manage many concurrent user interfaces, and the UIs themselves are platform and programming language-independent. The Home Controller has been used with WWW-based UIs (Java applets), mobile phones (Java/Symbian), graphical PC UIs (Java) and a speech control UI. Concurrency is an important factor since many UIs can be used at once, and possible state changes should be updated to all UIs as fast as possible. The Home Controller has no form of arbitration or prioritisation for UIs, though if multiple commands are received in a short time they will be handled in the same order as they were received. Whenever a state change in a device has been noted, the Home Controller sends an update to all UIs. Depending on the particular device, some devices are polled at regular intervals whereas others can be queried from an UI. The server uses a text-based protocol to communicate with UIs, keeping bandwidth and processing requirements simple. This is important, since some UIs use low-power microcontrollers with limited processing capabilities and relatively slow network connections. A text-based protocol is also programming language-independent, allowing UIs to be written in any programming language.

The Home Controller offers several different kinds of services such as timers, preset modes, grouping of devices and logging services. It also contains mechanisms to create artificial intelligence in the home environment. The intelligence is created in objects called tasks and these are adjustable from user interfaces and in turn they command the device objects. There are many kinds of tasks, but they all have a unique identification number. This number is used, for example, to find the appropriate task when one component is sending commands to another. Tasks have access to device-objects and thus they are able to manipulate physical devices. Apart from these common properties, the tasks can be very different: the simplest kinds of tasks are used for sending values to device-objects, so that user interfaces can adjust physical devices. Other tasks only monitor device-objects and notify user interfaces as soon as their state changes. Tasks can send commands to other tasks, and there are several different ways to group tasks. When commands are sent to a

group, the tasks belonging to that group are commanded in turn, usually after some processing. Some tasks are activated when certain conditions are met so that they can command other tasks in turn. New forms of intelligence can be added by designing new tasks, and new types of devices can be brought into the system by implementing the appropriate device-interface.

The timers that the Home Controller offers are available for every user interface. There can be an arbitrary number of timers, and each timer can execute multiple tasks upon activation. A timer can be set to repeat at any interval, or it can be activated only once and then terminated.

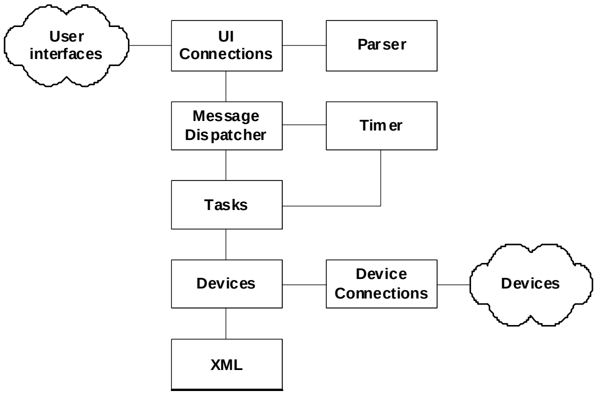

Figure 5.36 Components of the Smart Home server [Vainio06].

Software Modules Running on the Server

Currently the server PC runs the Home Controller core software, which in turn connects to other modules running on the same PC or throughout the Smart Home network. For speech control the SCARS software continuously monitors microphone inputs, ready to input the received sound to commercial speech recognition software (Philips Freespeech Viva). A learning fuzzy software module monitors behavioural patterns using sensors and actuators in the Smart Home, updating its database and performing tasks when appropriate. Another PC in the Smart Home runs a fingerprint scanner software, which compares fingerprints of people to a database, opening the door for authorised individuals. Once a positive match has been made it connects to the server, opens the door and outputs a welcome message using the SCARS interface.

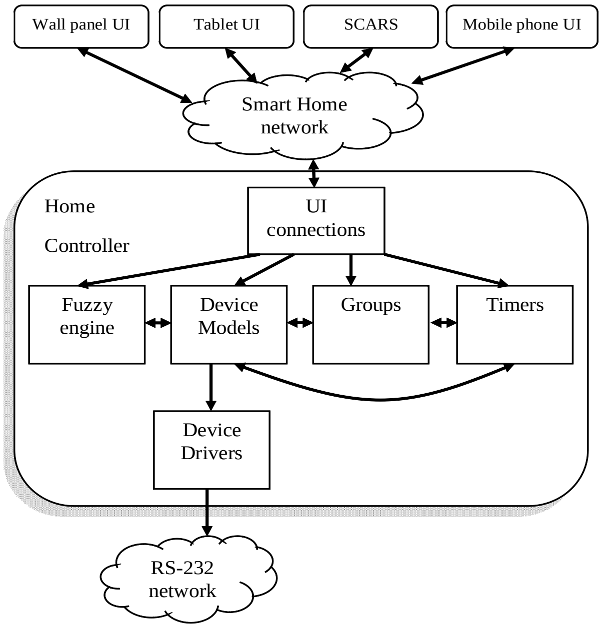

Figure 5.37 Block diagram of the Home Controller and its connections [Vainio06].

5.4 The eHome (2001-2005)

Because of the great deal of data gathered from the Living Room in the form of findings, material, ideas and theories, it was decided to validate these in practice. The eHome was a study that integrated everything that had been previously designed into a real home environment [Kaila08]. It is difficult to gain accurate and reliable results from laboratory studies, so a more practical approach was needed. As mentioned earlier, a smart home should be a relaxing environment and offer easy and intuitive ways for users to control devices. One key issue was security; users should not have to worry about forgetting to turn off lights or the stove after leaving home. With the help of technology many functions of the home can be improved while new kinds of UIs would add flexibility and new functions. The goal of the eHome project was to obtain results on using the Home Controller software, new UIs and hardware in daily life as well as finding out which technical solutions and services users would find most valuable. The eHome would become a unique study and also one of the few long-term smart home experiments involving a real living environment and users.

A 56 m^2 rental apartment in downtown Tampere was selected to become the eHome. This was equipped with devices and technology similar to the Smart Home with a home network, server, user interfaces, sensors and controllable electrics. The next important specification concerned the tenants and their profiles. They should be relatively young, willing

to experiment with innovation, allow random visits to their apartment (for evaluation, interviews and technical support) and most importantly they should not have a technical background. The apartment would be rented to them for a period of three years. After a few interviews a couple in their mid-twenties was selected: a male biologist and a female culture historian. The tenants were to provide researchers valuable feedback about the eHome and its functions, as well as ideas for further development. A usability researcher was present whenever a new UI was introduced or when regular feedback was collected to record valuable first time usage comments and experiments. The eHome contained several different user interfaces, including WWW-pages, programmable wall switches, mobile phones and a television UI. It also features control of electric sockets, lights, adjustable window blinds and different kinds of sensors. The emphasis of the eHome- project was on usability and practicality since it was not the aim to create an automatic system which would control everything without interaction from the users. The devices and user interfaces are designed to make everyday life easier and less stressful, the functions offered by the eHome being mostly informative, helpful and relaxing.

Figure 5.38 The eHome apartment building. The test apartment is on the ground floor, lower left.

The eHome-project started in 2001 in cooperation with private companies in the construction (Pohjola, Tampere rental apartments), telecommunication (Elisa, Nokia, Sonera) and electronics industry (Electrolux, Pikosystems) as well as usability researchers (TUT software engineering). The apartment was finished in late 2002 and the tenants moved in later that year. The apartment consisted of a living room, bedroom, kitchen and a bathroom/sauna and was modified to conform to the project's requirements. Like the Smart Home, the eHome had a suspended ceiling, customised electrics and extra space for cables and equipment. Empty cable ducts made it easier to install equipment and modify networks if nec-

essary, and the suspended ceiling conveniently functioned as installation space for equipment. A separate control room was built under the apartment in the basement of the building, which allowed the servers and network equipment to be installed out of reach of the users. It also made it possible to visit the eHome without bothering the tenants. A LI-NET network node was installed in each room, and the master control unit was wired to the server in the basement. Lights, sensors and controllable devices were also wired to the basement through the suspended ceiling, making installations tidy and unobtrusive.

Figure 5.39 eHome control room in the basement (top), electric distribution board showing relays and the LINET master box (bottom).

Installing electrics, devices and other hardware took a few months, after which the tenants were able to move in. The total cost of the installations was about 50 000 €, though a significant amount of this was invested in the adaptability of the structure, which would not be required in normal living conditions. The eHome was in use for three years, after which it was dismantled and concluded in late 2005. Some of the hardware items were reused in the Smart Home while others were kept for debugging and testing purposes.

Figure 5.40 Bedroom and kitchen in the eHome apartment.

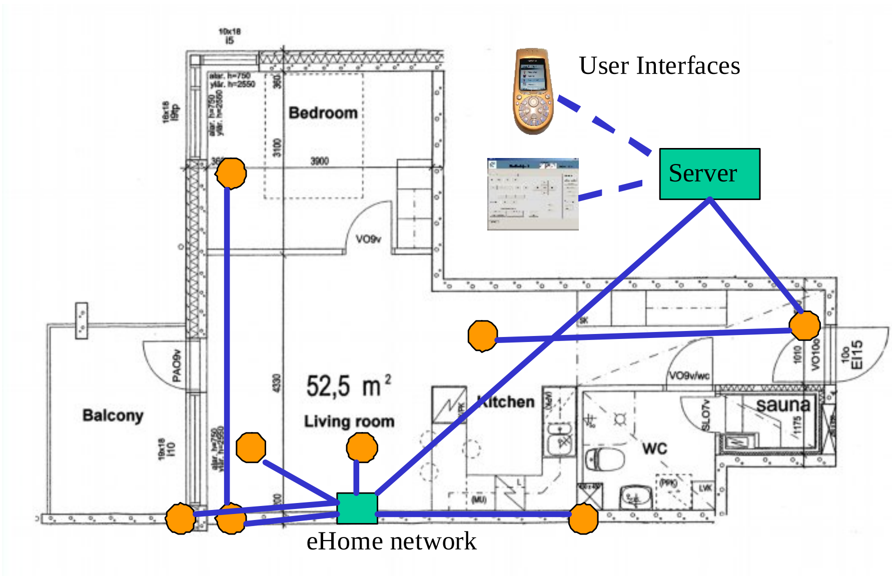

Figure 5.41 Floor plan of the eHome apartment showing devices (yellow dots), network connections (blue lines) and network components (green boxes).

5.4.1 eHome Networks

For the most part, the eHome contained the same networks as the Smart Home. Serial cables were used for most devices (sensors, actuators and LINET master) and RF transceivers were not required. Ethernet was used for connecting server and UIs together and LINET provided the control method for lights and mains sockets. The heart of the eHome network was a server PC, located in the basement. The PC managed connections to other UIs and running a web server in the home intranet and it also ran a modified version of the Home Controller middleware software. In addition, the PC had an ADSL connection to the university so that a remote connection could be made to the server if updates or adjustments were needed. The Internet connection was also shared by the tenants for purposes such as regular web surfing. Fig. 5.41 below shows the infrastructure of the eHome, different network types, UIs and hardware:

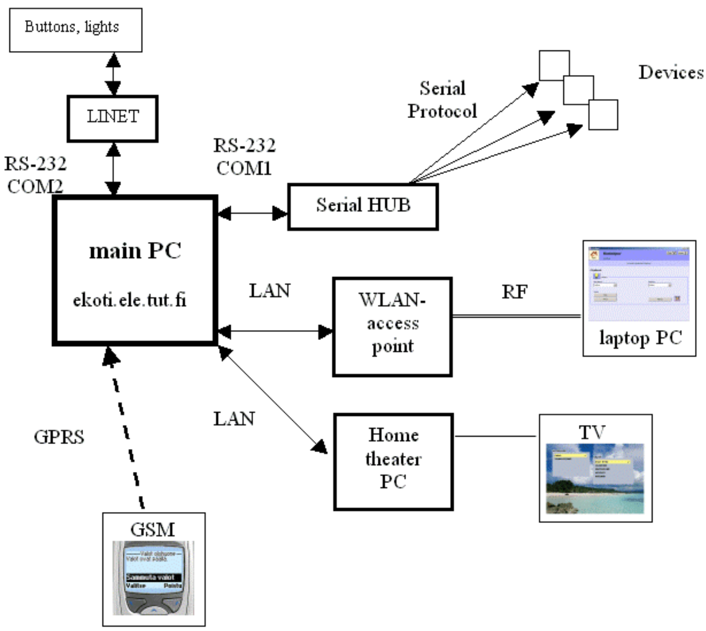

Figure 5.42 Network infrastructure of the eHome.

5.4.2 eHome Devices

The eHome contained devices in common with the Smart Home, including motorised window blinds, flower pot monitor, temperature and humidity sensors and halogen dimmers. Devices were first tested in the Smart Home and later transferred to the eHome. Since a duplicate network and devices existed it was easier to test different upgrades and changes before implementing them into the eHome.

Current Monitor

The eHome tenants reported their concern about forgetting to turn off equipment when they left their home, and to address this issue a method was needed to sense if a device was turned on or off. For this purpose a sensor module was designed that was capable of measuring the current drawn by a connected appliance. The device was essentially an extension cord, with a sensor unit in the middle. The sensor used a LEM [LEM] current sensor, which could measure the amount of current being drawn from the phase conductor. The sensor was connected to the serial hub using standard serial cables.

Figure 5.43 eHome current monitor.

5.4.3 eHome User Interfaces

Whereas the network and infrastructure in the eHome was similar to those of the Smart Home, the UIs were designed to be very different. The focus was not on home automation but rather on offering users various options for interfacing with home equipment. While static, traditional UIs were retained (light switches, window blinds etc.) new ways of controlling home equipment were created. Each UI was designed for a specific purpose and scenario, with emphasis still firmly on usability and practicality. UIs were designed in co-operation with usability experts to create intuitive graphical UIs that users would appreciate.

Figure 5.44 Collage of eHome UIs, showing the WWW-UI running on a laptop (top), TV UI (bottom left) and mobile phone UI (bottom right).

eHome WWW-UI

The primary UI for the eHome was a web page. The web page could be accessed from any PC in the eHome, but a Fujitsu-Siemens Lifebook laptop with a touch-screen was acquired as a primary terminal. From the laptop, users could navigate to the Home Controller page and make adjustments from there. The main page showed pre-set modes, timer and light adjustment options. The timer settings page contained settings for different kinds of timers; for example users could set all lights to turn off at midnight each working day. Timers could also be temporarily disabled if necessary. A drawing of the floor plan was shown on the light adjustment page, allowing users to click on a desired room and adjust the light levels from a slider on the right-hand side of the page. Individual lights could also be turned on or off by clicking on the icon on the floor plan. The primary purpose for the web UI was to allow users to make more complex settings, such as setting modes or timers.

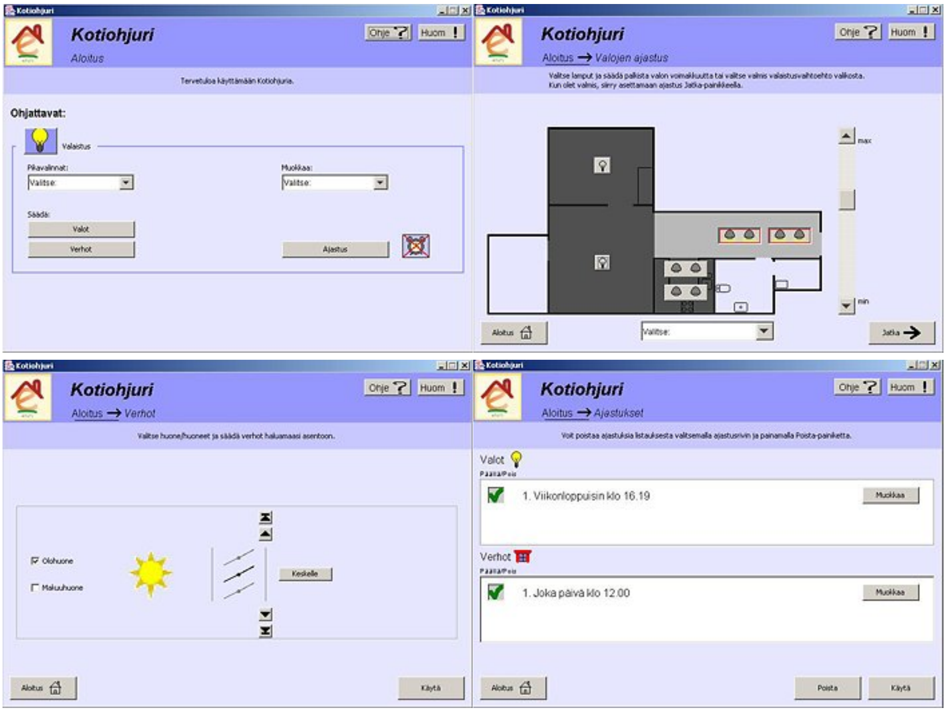

Figure 5.45 Screenshots of the eHome WWW-UI. Shown here is the start page (top left), lighting control (top right), window blind control (bottom left), timer settings (bottom right).

eHome Mobile Phone UI

The mobile phone UI was designed to run on a Nokia 6310 mobile phone. It was possible to load Java applets into the phone memory, and a simple Home Controller UI was written to allow users to interface with the Home Controller even from remote locations. The phone would use a GPRS connection, which connected to the eHome server through a secure tunnel via the university. The phone UI featured basic adjustments for lights, blinds, pre-set modes and it also had a special function to check the status of the coffee maker and turn it off if necessary. The primary function of the phone UI was to facilitate remote control of the home and to reassure by allowing them to check whether they forgot to turn off an appliance when leaving the home [Koskela04_2].

Figure 5.46 eHome mobile phone UI, showing lighting controls.

eHome TV UI

In 2001 digital set-top boxes and home gateways were introduced to the market with the belief they would become the centres of home control and entertainment. Multimedia gateways with audio/video controls, broadband network connections and video-on-demand promised instant access to TV channels, movies and Internet sites. Set-top boxes were to receive high-definition digital broadcasts and provide interactive services to viewers. This technology would also have made it possible to integrate smart home controls in the same unit, allowing users to control their home using remote controls and their TV set. However later in 2003 such forecasts proved false, and with interactive digital TV services being practically nonexistent (and later completely discontinued in Finland) these products failed to appear on the market. The eHome was thus also left without a home gateway, leaving the project without a TV interface. For this purpose a home theatre PC (HTPC) was used instead, mimicking a home gateway with Internet connections and media playing capabilities. The HTPC was connected to the TV set and had a DVD drive as well as an infrared receiver, allowing it to be controlled with a standard remote control. Software created a graphical UI on the screen and processed remote commands which were forwarded to the Home Controller server. The TV UI had similar controls as other UIs, the emphasis being on entertainment and commands related to TV viewing (lights, blinds, preset modes).

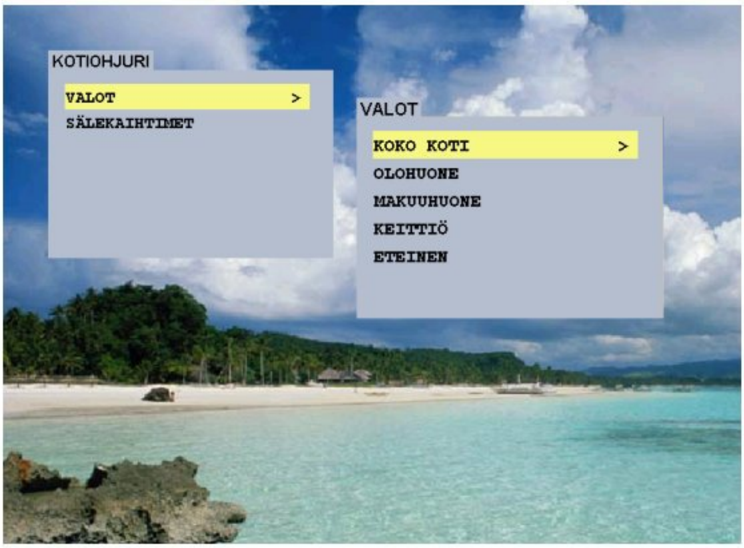

Figure 5.47 eHome TV UI, showing lighting controls.

5.5 Morphome (Living in metamorphosis) (2003-2005)

The Morphome - project (Living in Metamorphosis: Control and Awareness in a Proactive Home Environment) was a joint effort amongst TUT, University of Tampere and the University of Art and Design. Finding was from The Finnish Academy Research Programme

on Proactive Computing. Since the author was not directly involved in this project it is mentioned only briefly here.

Morphome [Mäyrä05] was started to discover how proactive home applications should be designed and since this was an interdisciplinary project, a non-technical approach was adopted. The project approached domestic life as human-centred experience rather than random interaction with home appliances. Another goal was to create new design methods for proactive technology [Soronen04]. In order to verify and test this theory, Morphome also involved testing in two pilot homes and other shorter-term tests with other families during the course of the project. Users were given a camera, a diary and a notebook that they could use to document their experiences with the new technology.

Prototypes constructed during the project include pillows that detect each others presence (emitting different sounds depending on the pillow they are next to), lamps that reacted to sound levels and ambient light and were able to slowly change colours, and an X10 based home network that adjusted lights in the home according to movement, sounds and pre-set timer settings.

Figure 5.48 X10 modules used in the Morphome project.

Findings of the project showed that multidisciplinary studies can provide results that cannot be gained from specialised studies through prototype engineering and user interviews. In addition, acceptability of new smart technology was surprisingly low among the testers, but this was considerably helped by the "softness" of the prototypes used in the tests (e.g. Morphome devices were not gray, boring boxes but instead friendly-looking gadgets that made the home more homely). Technology that contributes to domestic comfort and well being is more likely to be adopted than complicated technological gimmicks.

5.6 LIPS (Learning and Interactions in Proactive Spaces) (2007->)

LIPS is a project funded by the Academy of Finland that started in early 2007. Since the project is ongoing this chapter describes the current situation and future plans. The project is based on knowledge from previous smart home projects, the Smart Home and adaptive home control systems [Valtonen06]. The LIPS-project is aimed at researching adaptive technologies, environment modelling and user studies. A proactive, adaptive context-aware home requires little or no input and configuration from its occupants. This would lessen the burden on the users, make it simpler to add or remove devices from the home and make daily life easier by adapting to users' routines. The LIPS project research plan sets out the following objectives:

- To study methods for modelling of the environment and algorithms, to adapt the model and design a control system for a smart home test environment.
- To study interactions and context awareness in a home environment and to create unobtrusive and user-friendly sensing methods and user interfaces for controlling, and especially training, the home environment.
- To set up a test environment for validating the results with functional and user tests.

The project will use the Smart Home laboratory for user testing and for setting up the required infrastructure. A prototype network is to be constructed and devices from the Smart Home will be integrated using new network protocols.

5.6.1 Context Awareness

LIPS is being built around context recognition and context awareness. The prototype infrastructure will be tested and verified with a set of pre-defined contexts to determine the reliability of the recognition algorithm and the kinds of sensors that are required to accurately detect these contexts. In this case contexts are restricted to contexts of the user, not those of the space. In order to conduct tests and limit development time, all contexts are designed for a single user scenario. When there are several users inside the space it becomes all the more difficult to decide how to proceed. This is also due to the lack of a reliable, unobtrusive identification system that could be used for identifying and locating people inside the home. The primary focus is thus on the requirements of context recognition and creating the necessary infrastructure.

Three different contexts were defined; eating, watching TV, sleeping. Eating is determined as an action that takes place in the dining room. The context itself would be recognised by sensors detecting situations such as presence in the dining room, the presence of food or drinks (either hot or cold) on the table or the user sitting on a chair at the table. TV viewing is a more challenging context, as there are many situations when the TV is turned on but no one may be watching. Casual viewing, where the TV is on in the background, watching news in the daytime or watching a movie in the dark are all different scenarios and require separate modes for lighting, ambient sound levels etc. Detecting when the user is sleeping is easier; by using bed, sound and light level sensors it is fairly straightforward to determine if a person is sleeping in the bed or not.

These contexts are clearly insufficient for general use, and a major challenge arises when all the possible contexts in peoples' daily lives are taken into consideration, as discussed in Chapter 2. Accurately detecting a context and predicting the subsequent context is crucial for proactive computing, and thus of great importance in the LIPS project.

5.6.2 LIPS Software

LIPS middleware is being built around the core software used in the Smart Home. Previous experiments with fuzzy logic and adaptive home control software [Valtonen07] have already provided a foundation for building further functionality. The control software is constantly monitoring the user's actions and recording every event. If the user makes an adjustment when a context has been recognised, it is recorded and taken into consideration. If the user has to perform the same adjustment multiple times it is an indication that the system is doing something wrong in that particular context. To correct this, the system learns the new settings and sets itself to perform them automatically next time the context is recognised. In this way users can teach the system to perform certain functions automatically when a context has been recognised. In terms of the actions and adjustments performed by the user, a challenge lies in distinguishing between those that are relevant to the current context and those that are not. For example, the user might be in the habit of washing clothes in the washing machine in the evening and watching TV at the same time. However, this should not imply that whenever the washing machine is detected running in the evening that TV should also be turned on. Such discrimination will become hard to perform, especially when new sensors and appliances can appear in the home at anytime. One option is to let the user decide which sensors and devices are relevant to a given context.

Context awareness can be used in conjunction with communication with other remote users. Instant messenger applications have become very popular, and users frequently share messages, files and data over the Internet. A similar application is being designed for use in LIPS, named "Context Messenger". This application would be used in a similar fashion as other messenger applications, but the detected context of users will be available to other users. This allows people to see what others are currently doing. Data for the context information will be collected by various sensors in the Smart Home; time, date and learned data in the context recognition engine. The Context Messenger will also have a more important role, functioning as a primary interaction point between the user and the context recognition engine. If a new context is detected, or changes in known contexts are recorded, the user can be greeted with a pop-up window requesting input on details of the context data. This function is generally needed initially, when new activities and contexts are being recorded. Later, as the system has gathered more data, the amount of interaction required will be significantly less. The Context Messenger is designed to run on a wall-mounted panel display, but other platforms are also under consideration.

5.6.3 LIPS Hardware

In previous projects almost all hardware has been designed in-house at the university, but in LIPS a decision was made to move to a commercial standardised platform. Initially two options were evaluated, Scatterweb [Scatterweb] and the mote platform, developed by UC Berkeley [moteIV]. Both were battery-operated wireless sensor platforms, with embedded sensors, a transceiver, some memory and a microcontroller (both are presented in further detail in Chapter 6.11). Due to the popularity and maturity of its software development kit, the mote was chosen as the primary platform for LIPS. The tmote sky module contains a MSP430 microcontroller, 1024 kB flash memory, 2.4 GHz 802.15.4 compliant radio transceiver, USB connector and humidity/temperature sensors. A mote node is powered either by two AA-size batteries or by a DC power source and the radio has an effective range of 125 m, which is sufficient for general indoor communication. Motes are usually programmed to run TinyOS [TinyOS], an operating system that has been specifically developed for sensor networks and other mote applications. TinyOS applications are programmed using NesC [NesC], a dialect of the common C programming language. The modularity and popularity of the TinyOS software platform makes it possible to use motes for many purposes, and many kinds of application software can already be found on the Internet.

New devices will all be connected to the home network using motes, legacy devices connected will be either using existing networks or connecting them to the serial port on a mote. One problem remains, however: the serial port on the mote is shared with the radio transceiver, and thus care is needed to ensure that these two do not conflict. Additional sensors are also required for detecting contexts, and for this purpose new sensors are also being installed in the Smart Home.

Sensors

Sensors designed for LIPS are intended to complement the sensors already present in the Smart Home. Some sensors are already being obtained automatically since the mote sensor boards that are used for wireless networking already include temperature and humidity sensors. For context recognition there is also a need for more sophisticated and specialised sensors.

Location Sensor

To determine the location of the user, the Smart Home is being equipped with a capacitive positioning system [Valtonen09]. These sensors can detect a person’s location with 30 cm accuracy, and they will be installed in every room (except the bathroom and sauna). The system can be used for tracking people and also to determine whether they are seated, standing or lying down. Another sensor is installed in the couch near the TV, which will report if users are sitting on the couch. Additional sensors can also be installed in chairs around the coffee table in the living room.

Table Sensor

For recognising the eating context the dining room table will also be fitted with various sensors. Under the wooden tabletop, directly beneath the veneer surface, a matrix of temperature sensors will locate cold or hot objects on the table top. Capacitive strips between the sensors can detect the presence of conducting material, e.g. fluids. An infrared sensor can detect if a person is sitting directly in front of the table. With these sensors it should be possible to detect with reasonable accuracy when people are sitting at the table having lunch.

Living Room Sensors

A few additional sensors are also needed in the living room. The TV set is equipped with a serial port, and with a mote connected to this port it is possible to obtain various types of information from the TV (e.g. turned on/off, which channel is being watched etc.). This information is useful for determining how the TV is being watched. Additional information can be retrieved from a microphone sensor, which also uses a mote for measurement and communication. The microphone records only sound levels and performs no additional filtering or frequency discrimination. Sound levels are used for detecting whether people are talking, listening to something or relaxing in quiet.

Sensing in the LIPS-project is designed to be unobtrusive so as not to disturb the user or be in any way conspicuous. This also means that there are to be no wearable sensors or actions required of the user in order to perform a measurement or detection. Floor sensors can function without the user noticing them, and presence and biosignals can be recorded remotely with a Doppler radar [Zakrzewski06].

5.6.4 Service Discovery

In order to keep track of all devices, sensors, actuators and their functionalities in the home, a dynamic protocol that can easily adapt to changes is required. A hard-coded piece of software, such as the one currently running in the Smart Home, is unable to deal with a situation where a sensor fails or a new device is connected to the home network. In the former case, the sensor reading will simply be unavailable and in the latter nothing will happen with the new device until the server configuration is changed manually. An adaptive dynamic protocol would allow the system to locate another temperature sensor nearby and use its temperature data instead, and in the case of a new device it would be able to identify it and utilise its functions and facilities. Network and device reconfiguration also requires no action on the part of the user, making it simple to install new devices, move them around the house, and modify the network topology. Service discovery is discussed in more depth in Chapter 7.

Because LIPS is based on new hardware with stricter requirements for data transfer and service discovery, it also requires a new communication protocol that would replace earlier serial protocols. The protocol is presented in Chapter 7.

5.6.5 World Modelling

In order to capture contexts and adapt to users' actions the system requires a model of the environment. One option is to build a model using sensor measurements for building a "mountain model". Assuming that sensor measurements have a particular of distribution (for example, they might be normally distributed), they are used for building a two-dimensional "mountain" that grows in height as measurement results increase. This means that sensor data for one event or context becomes more frequent, it is accumulated and stacks up. When this "mountain" is high enough at a certain point, it will be registered as a context, as illustrated in Fig. 5.49.

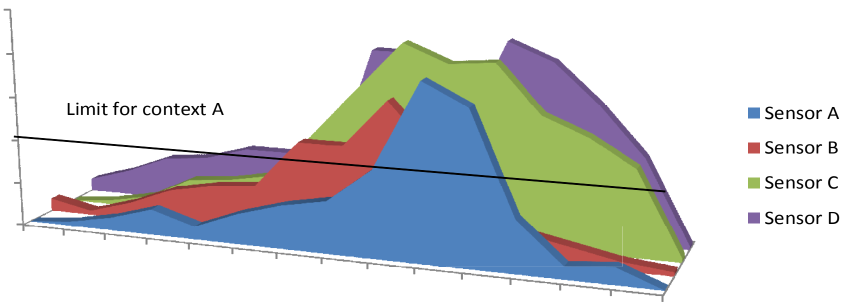

Figure 5.49 LIPS mountain model, showing data from four different sensors.

There is also a clear need for a physical model of the space, mapping rooms and locations onto a coordinate system. This model is also used for positioning and fixing coordinates for devices according to the rooms they are in.

5.7 Summary

Smart home research at TUT has been conducted for ten years, and during this period three different smart spaces have been constructed and two additional smart home projects completed. The result of these projects has been valuable knowledge of software and hardware design for smart home applications, physical testing spaces and home control middleware. Research in the Smart Home will continue in conjunction with the LIPS project, and development and maintenance of the apartment will also proceed.

The table below presents a short summary of TUT smart home projects:

Table 5.1 Summary of TUT smart home projects.

Project	Main Themes	What's new?	Year
Living Room	Relaxing, activating, informative	Home network, wireless technologies,	1999-2002
Smart Home	Different kinds of UIs, more control options	Home UIs, fuzzy control system, Home Controller middleware	2002->
eHome	Multiple UIs, User studies, customisation	Mobile UI, WWW-UI, home environment testing	2001-2005
Morphome	Proactive home applications, interdisciplinary design	Different design prototypes, new design principles	2003-2005
LIPS	Proactivity, adaptive software, service discovery	EPIS protocol, mote network, context recognition	2007-2009

The figure below illustrates how the focus of different smart home projects at TUT have evolved:

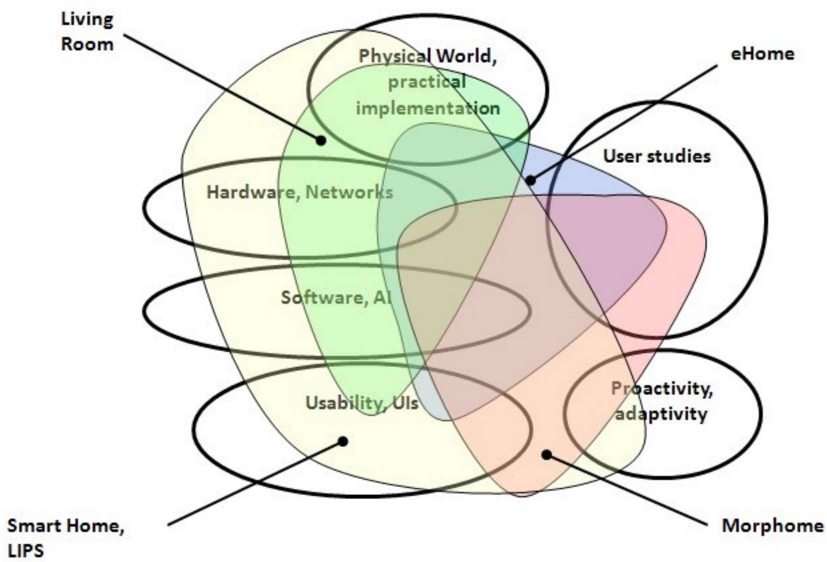

Figure 5.50 Overview of TUT smart home projects, showing overlap of research areas.

Compared to the other research projects presented in Chapter 4, TUT smart space research has had adopted a slightly different approach. From the outset, the emphasis has been on a practical approach using current standards and affordable components. Whereas some other projects have concentrated on simulations and interviews, all TUT implementations have involved real physical hardware. This has enabled us to perform practical testing, verification of the functionality of our designs and to identify practical usability issues. Most important, all designed prototypes and applications have been connected to the home infrastructure to make the system function as a single entity instead of a collection of numer-

ous small, independent components. Interaction with the smart home system has been confined to various physical UIs and control methods; more exotic variations such as gestures and emotions have not been used as these require significantly more signal processing and are more difficult to detect accurately. Since many projects have been funded by the Academy or the department, most of the research has been free of commercial emphasis or interest and no constraints have been imposed by third party services or partners.

Each project has had its own focus: the Living Room emphasized comfort and user activation, the Smart Home compatibility and integration, the eHome user tests and usability and LIPS will concentrate on adaptivity and proactivity.

6. Hardware Aspects

The backbone of a smart home is formed by networks and devices that perform measurements, adjustments and transfer information. This chapter describes the various choices that smart home designers face, available hardware and a discussion about various related aspects. Hardware that has been used in TUT smart home research has been previously presented in Chapter 5.

Devices in a smart home include sensors, actuators, home appliances, entertainment devices and computers. Devices can be categorised according to their processing power, intelligence, designed purpose and other features. The following figure illustrates a categorisation that has made in terms of the perceived visibility of one device (e.g. how users perceive it, if it is clearly visible when used, or if users are unaware of the technology they are using) and the capabilities that the device possesses (e.g. the amount of processing it is able to perform and its level of "intelligence"):

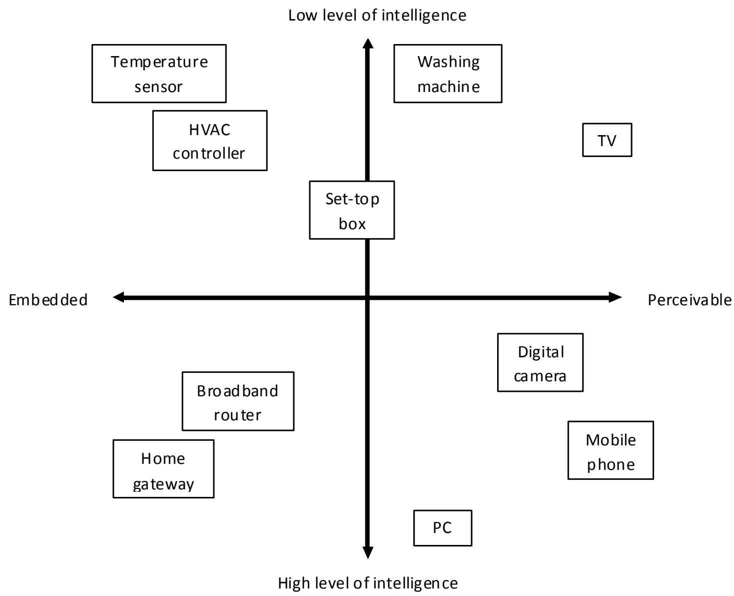

Figure 6.1 Classification of typical home devices according to how intelligent and perceivable they are.

For example, a TV set is clearly visible to the user but a digital set-top box is less apparent, as users are still "watching TV" even if the broadcast is being received by the set-top box. A modern digital camera is capable of processing large amounts of image data, and it also actively analyses the image content, recognising faces, movement etc. Simple sensors are inconspicuous and numerous while their other capabilities remain very limited. Network-related devices, such as broadband routers or firewalls actively monitor traffic, filter it by

content and source/destination addresses and decide on appropriate tasks. A home gateway is a more complex device, being capable of interconnecting home networks, bridging protocols and network standards and connecting the home to the Internet.

6.1 Networks

The vision of ubiquitous computing relies on a network infrastructure to facilitate communication between user interfaces, sensors and surrounding devices. The kind of network actually used does not really matter provided it is compatible with all devices. There might never be a single, universal network that would become a de facto standard for domestic use and instead it is more likely that the home network will continue to consist of multiple network types [Aldrich03]. Home networks are used for inter-device communication, communication with user interfaces and communication with the home server or gateway. Networks that go out of the home are used for connecting to the Internet, phone lines, cable TV, etc. The following figure illustrates different communication networks related to homes:

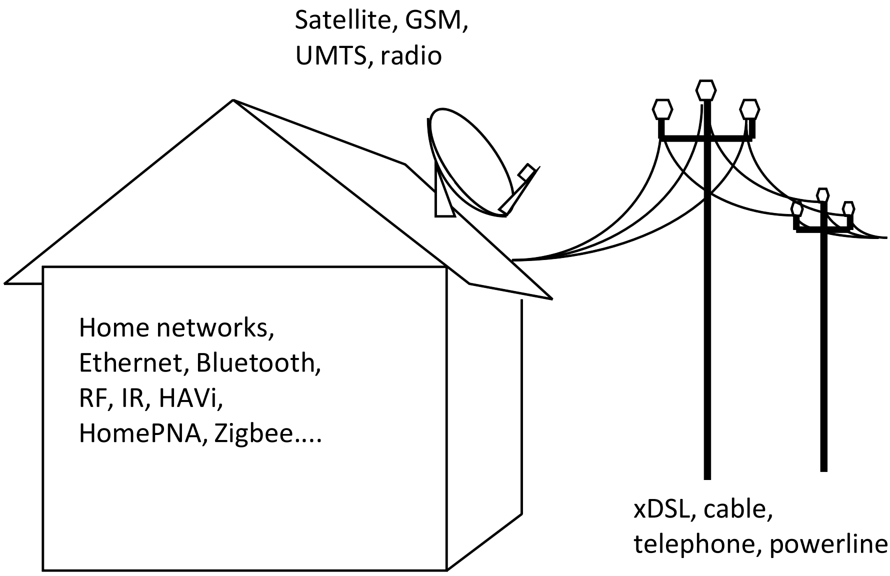

Figure 6.2 Network connections inside and outside the home.

The network is crucial for transporting messages and data from one place to another but also for making it possible to query devices in the network. This way devices and user interfaces can learn the status of each other and update information when necessary. For example, a user interface always needs the most recent information so it can display the status of all connected devices properly. To make this possible the networks used must be bi-directional; it must be possible to send data both to and from a device [Chatterjee98]. This is different from some traditional home automation networks, which only allow commands to be sent to devices in one direction. For example, a timer can command the lights

in the building to be turned on, but if someone else manually turns the lights off afterwards, the network controller has no way of knowing this without this feature. As far as the controller is concerned the lights are still turned on. Bi-directionality is also important for verifying that commands have been received, making reliable transmissions possible. However, existing devices that use only one-way communication, such as remote-controlled home A/V equipment, should also be considered. If there is no feedback through the network it needs to be enabled another way, for example visually through the user. If an infrared transmission is sent to a device but there is something blocking the communication (for example, a person standing between the transmitter and the receiver), the signal will not be received. The only way for the system to be aware of this is to indirectly monitor the device (by measuring current consumption, operating mode, etc.) or by having the user re-transmit the command.

Networks in a home environment can be divided into five different categories according to range, application and distribution:

Wide Area Networks (WAN)

Wide area networks, as the name implies, cover wide geographic areas larger than cities or communities. WANs connect LANs and larger area networks and cross national boundaries, as the Internet does, for example. Typically, WANs use telephone lines, satellite or microwave communications.

Local Area Networks (LAN)

LANs cover smaller areas, such as homes, offices or airports. Typically LANs have high data transfer rates and rely completely on internal infrastructure. LANs can be connected to other LANs using secure means, for example, VPN. LANs use Ethernet, WLAN and they can be connected to WANs using cable modems, DSL modems or routers.

Personal Area Networks (PAN)

PANs are defined as the communication network in the immediate vicinity of the user (within a few metres), including information appliances such as PDAs, computers and mobile phones. PANs are used for peer-to-peer communication between devices or for connecting a device to the Internet. WPANs (Wireless PANs) use wireless communications, such as Bluetooth or IrDA, instead of cables.

Body Area Networks (BAN)

Body area networks take a step closer to the user. Sensors for measuring movement, biological quantities or similar parameters can be worn or integrated into a device or garment that the user is using. Devices communicate through special short-range networks, usually wirelessly, and data is collected into a UI device or stored and transmitted to a base station at a later stage.

Intrabody Network (IBN)

Intrabody communications take place between devices implanted inside the human body (or swallowed) measuring various parameters, such as blood viscosity, glucose levels, and ECG. With IBNs care has to be taken when transferring data, as safety margins should not be exceeded when transmission takes place this close within the body. Implants can use RFID for communication, or alternatively connect to the BAN.

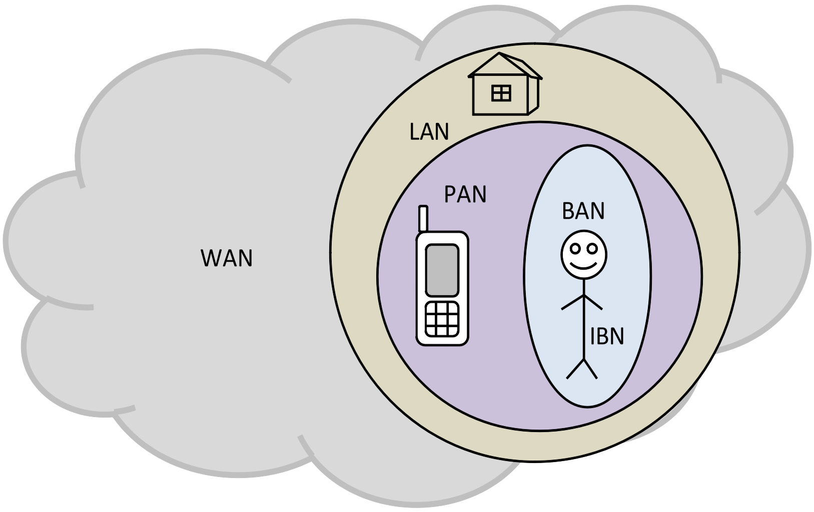

Figure 6.3 Illustration of different network categories, from intrabody networks to wide area networks.

6.1.1 Selection Criteria

When networks are compared and considered for smart home applications there are a number of factors to be considered. The following list presents a few of the more important ones:

Range - With wired networks there are practical limits on the length of cables, and wireless networks naturally also have a limited usable range. Range is closely linked to power usage, and thus power savings can be achieved by sacrificing range.

Bandwidth - It is always good to have spare bandwidth, as it makes it possible to transfer large amounts of data without overloading the network. However, in order to save cost and energy, it is usually wise to choose the most appropriate network technology for a particular application.

Energy consumption - In wired applications energy consumption is usually not a crucial design factor, but in wireless cases this becomes paramount. Energy consumption is often a compromise between performance, range, features, response time and mobility. Robust-

ness, encryption and complexity often dictate the power consumption of a wireless transceiver chip, for example.

Cost - Smart home technology, i.e. the hardware itself, is rarely a factor. For example, devices created at TUT use widely available components and an individual device typically costs less than ten Euros. Certain sensor modules, complex integrated circuits etc. can still seriously increase the cost of a device, as will the amount of time spent on its design.

Size - Size matters especially with mobile devices, but also when installing or retrofitting fixed devices. The physical size of a network connector or a battery often limits the practical minimum size. Cost might also be a factor as smaller components can be more expensive and difficult to install.

Scalability - Networks are by nature designed to be scalable, but in many cases there are practical limits on how many devices or nodes can be connected at the same time. Limits can also be imposed by power consumption (a network can sustain a certain number of nodes before maximum power output is reached) or delays (network cables can be of certain length or messages can hop through a certain amount of nodes before delays become too long). Finally, processing power or memory restraints can dictate the amount of traffic or the number of nodes a network can sustain.

Reliability - Wireless networks are inherently less reliable than wired counterparts, but nonetheless reliability and the ability to cope with errors, noisy environments and other points of failure are very important in a smart environment. Error correction, the possibility to resend corrupted data and collision detection are examples of methods to cope with such problems.

Complexity - To the user networks should be as invisible as possible; there should be no addressing, installation or setting up required of the user.

Standardisation - Possibly the largest problem with smart environments is the myriad of different standards that exist, especially for networks. However, since it can be difficult or impractical to use only one type of network, interoperability has to be considered carefully in the design process.

Latency - Here latency is the delay that data undergoes from the time it is sent from one device to the time it is received by the target device. If latency becomes too great it can adversely affect the functionality and response time of a smart home system, as messages arrive too late to react accurately to events in the home. High latencies are also easily perceived by users and they can cause frustration or be misinterpreted.

Privacy - Concerns regarding privacy and security are understandable and of major importance to users of smart homes since the amount of data that is being gathered is very large and of a sensitive nature. Tapping into wired networks requires physical access but wireless networks leak outside the home and thus have to be adequately protected against outside intrusion. Strong security measures, such as biometric identification, should also be considered for remote access to home controls.

Bi-directionality - This is not a problem with most networks, but there are still some legacy or wireless networks that work only in one direction. This is a problem for smart home applications since commands cannot be verified and the status of the device cannot be enquired. Bi-directionality is also required for updating the software of devices through the network.

Networks that are designed for industrial and larger-scale applications (for example, LON, CAN bus, etc.) might be too expensive and unnecessarily complex for domestic use. Fortunately, simple devices, such as temperature sensors and light controllers only send a few bytes at a time and have no need for high-speed megabit-range networks. Simple low-cost networks can be used, keeping installation costs and energy consumption low. User interfaces and more complicated devices, on the other hand, benefit from low latency, higher speed networks. Latency is critical especially with user interfaces, as delays can be annoying and confusing in terms of usability and reliability. Some devices produce data that has to be continuously sent or measured and thus require networks with higher bandwidth. Furthermore, video surveillance and computer vision applications have similar requirements, as even compressed video generates large amounts of data. Thus it would seem appropriate to select the optimal network for every application, taking into account the requirements, price, performance and compatibility of each network type.

6.1.2 ISO / OSI Network Model (OSI Seven Layer Model)

The International Standard Organization's Open System Interconnect (ISO/OSI) model is widely used for describing layered network communications and network protocols [Tannenbaum02]. The OSI model describes how data is moved between the independent layers and divided into tasks that the seven layers perform. The purpose of a layer is to provide services to a layer above it and to receive services from the layer below it. Layers are transparent, so that the transport layer of a device is able to communicate directly with the transport layer of another device. The layers of the OSI models are presented in the following table:

Table 6.1 OSI model layers and their functions.

	Data Unit	**Layer**	**Function**
End-to-end communications	Data	Application	Provides services to applications
-”-	Data	Presentation	Encryption, data presentation
-”-	Data	Session	Session management
-”-	Segment	Transport	Connections, reliability
Inter-device communications	Packet	Network	Logical addressing, path determination
-”-	Frame	Data Link	Physical addressing, data format
-”-	Bit	Physical	Media, signal transmission

The physical layer is responsible for transmitting data through a physical communication medium, whatever it might be. The physical layer is very close to the hardware, for example it knows how many volts a logical “1” has to be, and what modulation is used.

The data link layer defines the format of the network data (checksum, addresses etc.) and divides data received from the physical layer into frames. It is also responsible for flow control and checking for errors during the transmission.

The network layer is responsible for wrapping data received from the data link layer into packets and relaying them to the appropriate recipient. It also has to manage routing, i.e. choose the best path (shortest or the one with the smallest delay, for example) to the destination.

The transport layer receives data from the session layer, divides it into blocks and ensures these arrive at their destination in the correct order. It also adjusts the transmission speed so that the recipient is not overwhelmed with data.

The session layer creates a session between two participants. It controls opening, maintaining and closing the session, and also resuming it after an interruption.

The presentation layer is not concerned with data transfer anymore, its primary task is responsibility for encryption/decryption and, as the name implies, the presentation of data (semantics, format, character sets etc.).

The uppermost layer is the application layer, which is the layer that is visible to the user. This provides different kinds of protocols for applications (for example e-mail, FTP, telnet).

Another network-related term is Quality of Service (QoS). QoS is not directly an indicator of achieved service quality but rather a guarantee of performance for applications [Cisco03]. QoS contains control mechanisms for reserving resources in a network, for example, required bit rates, maximum error rates or maximum delays. It can be used to prioritise different kinds of data according to their requirements, ensuring important data receives high priority (especially in congested networks). For example, delay-sensitive applications, such as voice over IP (VoIP) benefit from low latencies and guaranteed data rates.

6.2 Wired Communication

The first wired communication media were telegraph and telephone lines, and even if the traditional switched telephone network still exists across the globe other more modern networks are slowly taking over. Generally wired networks are robust, dependable, fast and cost-efficient but even if the hardware itself is inexpensive compared to wireless alternatives, installation work can involve high cost. Wired networks are highly resistant to interference, and they offer a broad range of communication speeds and in some cases they also supply power through the same cable. Wired networks can be connected to other types of

wired networks using adapters and converters to take advantage of the superior qualities of another network, or the same physical cable can be used to house multiple different signals. Thus it is possible to use traditional electrical or phone cables for data transmission with appropriate transceivers, for example, making powerline communication and DSL modems possible. The disadvantage of these solutions is increased complexity and cost since they require special adapters and converters. In apartment buildings it is also difficult to filter out the signals emitted from each apartment, and neglecting to do so would create interference, security issues and other unwanted effects.

Wired networks are durable, but are also still prone to corrosion and physical damage from excavators, drills and mechanical stress. Ohmic losses and other unwanted effects also dictate maximum lengths of cables, which for 100 Mbit Ethernet means a maximum cable length of 100 metres, for example. Wired networks in a home can be divided into four categories: electric cabling, phone cabling, audio/video cables and data cables.

6.2.1 Wired Network Types

Traditionally wired communication in embedded electronic systems is done using proven technology, such as by using RS-232 serial cables. Serial ports are common in computers and controllers, although they are being rapidly replaced by USB ports. However, RS-232 is not a network; it only transfers data between two devices (point-to-point communication). A proper network with common cables can be implemented using the RS-485 standard, which allows for megabit-speed networking over a distance of hundreds of metres.

Legacy cabling in the home can also be used for networking. Powerline communication using mains cables makes it possible to transfer data inside the building without requiring any other infrastructure. X10 [X10], LonWorks [LON] and HomePlug [HomePlug] are examples of such technologies. The simplest version, the X10, is able to transfer only simple on/off commands whereas the more advanced standards are designed to replace Ethernet cables. Problems with powerline communication include causing interference and being susceptible to it. Phone cabling has been adopted much more successfully, making it possible to deliver Internet communications to end users. From the first slow analogue modems that were able to transfer up to a few kilobytes per second, faster and more reliable DSL modems quickly took over, offering transfer rates up to tens of megabytes per second. Phonelines can also be used inside buildings (for example using homePNA), connecting apartments to a common DSL or leased line.

Standardised CAT-5 Ethernet cables [Cisco03] are becoming a de-facto standard in modern homes, as it is possible to use them for several purposes. The same RJ-45 connector is installed in every room, and from the switchboard it is possible to re-route the connectors to become phone, audio or antenna jacks or Ethernet ports. Thus re-routing and modifying the layout is possible at a later stage, making it easier to move the TV set or computer into another room, for example. If an appliance requires an Ethernet connection it is simple to connect this socket to the home router in the switchboard. Current copper Ethernet networks reach speeds up to 10 Gbit/s, providing enough bandwidth for domestic communication applications. Optical counterparts are used mainly for high-speed trunk networks

and high-bandwidth multimedia, but they can also have use in other demanding applications.

CEBUS (Consumer Electronic Bus) is a set of standards for household networking developed to succeed the older X10 standard and to create a standardised way for devices using infrared communication. CEBUS [CEBUS] can be used together with several kinds of transmission media, including coaxial wires, power lines, twisted pair cabling and wireless RF or infrared. All media are capable of transfer data at a rate of 8 kbit/s and in addition to this control channel, there can be extra faster data channels for transferring audio or video. CEBUS is not confined to a specific network topology or server, instead control is distributed among routers and devices.

EIB (European Installation Bus) is a European network communications protocol for building automation. Nowadays it is known as the KNX and administered by the Konnex Association [KNX]. KNX is compliant with EN 50090, the European Standard for Home and Building Electronic Systems. The EIB/KNX standard aims to connect all electrical functions of a building into a single functional network. HVAC, lighting and security are all controllable with a single system. The standard includes three levels of configurations that devices can have (A, E or S mode), ranging from “plug-and-play” zero configuration to fully customisable hardware. Physical interfaces for KNX include twisted pair cabling, powerline networking, radio, wireless and Ethernet. Networked devices can range from small 8-bit microcontrollers to PCs, using various operating systems.

Other kinds of communication interfaces can also be used, for example HAVi [HAVi], which is a based on IEEE 1394 (Firewire). HAVi allows home audio/video devices to be connected using embedded middleware, making it possible to share content and offer services to applications. One practical limitation, however, is caused by the maximum cable length of 4.5 metres.

Proprietary networks also exist, for example, LINET (described in Chapter 5), which is primarily used for controlling lights and electrics and LonWorks [LON], which is mostly used in larger office buildings and industrial applications. The following table summarises the properties of different wired networks.

Table 6.2 Comparison between wired network types.

Network	**Max. data rate**	**Topology**	**Max. cable length**
Ethernet 1000-BASE-T	1 Gbit/s	point-to-point / tree	100 m
HAVi	400 Mbit/s	point-to-point / tree	4.5 m...100 m
EIB	1200 bit/s (powerline), 9.6 kbit/s (twisted pair)	several	depends on media
CEBUS	8 kbit/s	several	depends on media
RS-232	115 kbit/s	point-to-point	15 m
RS-485	100 kbit/s..35 Mbit/s	multipoint	1.2 km

Table 6.2 Comparison between wired network types.

Network	Max. data rate	Topology	Max. cable length
X10 (powerline)	20 bit/s	star	100 m
LonWorks	5.4 kbit/s (powerline), 78 kbit/s (twisted pair)	several	depends on media

6.3 Wireless Communication

Wireless communication is a good alternative if cabling is too expensive or complicated to install. Usage of wireless networks is more flexible and cost effective when cables are not required and mobility is required. Most wireless communication uses radio frequency communication, which can be divided into three groups depending on the frequencies that they use: narrowband (kHz range), spread spectrum wideband (MHz range) or ultra-wideband (GHz range).

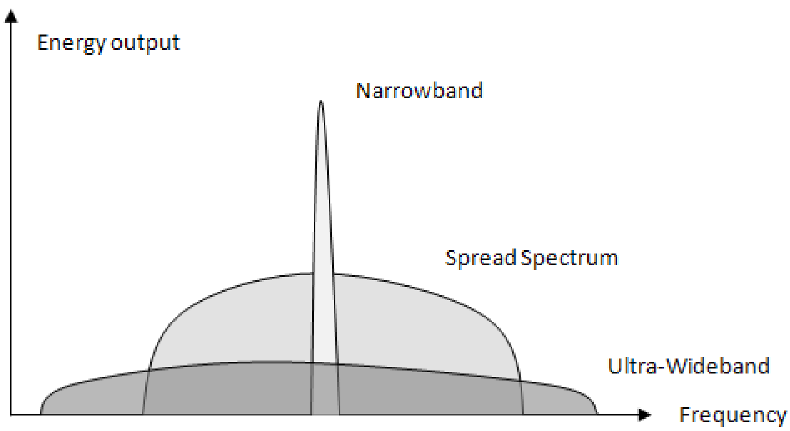

Figure 6.4 Spectrum graphs of different wireless communication technologies.

The many existing technologies provide several options to choose from, possible issues being mostly current consumption (Wireless LANs), short range (Bluetooth) and reliability (short range RF links). Another problem is the limited amount of frequencies available, creating overlapping frequency bands. Even when using a single wireless network type the maximum number of active network nodes is usually limited. Problems can already be seen between WLANs and Bluetooth links which disturb each other quite heavily, as measurements conducted in the Smart Home have shown [Myllymäki03]. Since wireless signals also propagate outside the intended space, there are also potential security risks. Without adequate security measures and encryption, signals can be intercepted by other parties, or they can simply interfere with another network nearby, considerably reducing the usable range. Thus there is poorer reliability with wireless networks than with wired alternatives.

With wireless networks it can also be difficult to debug if problems occur; a connection can work perfectly one moment but become unreliable at another. Electromagnetic conditions change constantly, so it is impossible to predict the future reliability of a wireless link. To users this would appear only as a general malfunction in the smart home system.

Bluetooth can easily be made to replace wired serial links, since the protocol directly supports serial port emulation. Modern mobile phones include sufficient Bluetooth functionality, and with proper software they can be made to function as user interfaces and controllers for the home network. Bluetooth, as used in the Smart Home, has sufficient range for indoor usage, and compared to text messages, for example, is free of charge to the user. An example of using Bluetooth in a smart environment is the BluePost, a smart remote-controlled car heating system [Kaila05_3]. Recently a low-power version of Bluetooth (Bluetooth low energy) was developed, making it possible to include Bluetooth into even smaller devices than before [BTLE]. Another similar technology is ZigBee [ZigBee], based on the IEEE 802.15.4 - standard. ZigBee is also a mesh radio network technology designed for low speed and low power applications. Zigbee has been specially designed for automation, sensor networks and mobile applications.

Recently several manufacturers have launched low-power single-chip RF transceiver modules and similar solutions onto the market. These offer a viable alternative to cabling, and the data rate (typically in the range of 20...200 kbit/s) is sufficient for sensors and actuators. A single-chip solution makes it possible to create miniaturised battery-operated sensor modules; a small antenna and a few passive components are all that is required for a matchbox-size transceiver. The effective range is enough to cover the an apartment or a large room, and with proper alignment and larger antennas it can be enhanced further. One example of such a network is ANT [ANT], which is a low-power sensor network radio transceiver that houses an efficient protocol and an 8051-based microcontroller. ANT is designed for sensor networks and its performance is less than excellent, however it is optimised for very low current consumption. ANT protocol is capable of forming simple point-to-point networks or more complex mesh networks, and it is widely used in sports, health and other personal gadgets.

Z-Wave [ZWAVE] is a wireless low-power communication standard developed for home automation. Standardised by the Z-Wave alliance, it is targeted for controlling home electronics, devices, lighting and household appliances. The Z-Wave network is a mesh-type, with multi-hop capabilities and a central controller that contains routing tables and data of devices included in the network. Operating at 868 MHz, it can achieve an operational range of about 30 metres inside a home environment. Devices can be added to the network by pairing them with the network; the device registers other devices nearby and their respective signal strengths.

For higher bandwidths wireless LANs offer a flexible alternative to fixed Ethernet cabling. However, their higher complexity and large power consumption make them less desirable for low-power sensors and battery-operated devices. WLAN access points may be required in several locations to guarantee sufficient coverage, but there are only a limited number of radio channels to choose from. Overlapping frequencies cause WLAN access points to interfere with each other, effectively reducing their usable range. There have also

been other competing wireless standards, however many of them have fallen into disuse. This is the case with HomeRF [HomeRF], a wireless home networking standard prepared by the HomeRF Working Group and HiperLAN [HiperLAN] (High Performance Radio LAN).

Wireless optical transmission is also still largely in use, however mostly in the form of unidirectional infrared remote controls. Infrared can also be used to create a home network, but range and physical obstacles can severely limit its applications. IrDA [IrDA], still available in laptop computers and mobile phones, offers relatively high data rates (up to 4 Mbit/s). However, since its range is limited to less than one metre it is not a viable alternative for smart home applications.

Other short-range wireless technologies include RFID [Hossain08], which is mostly used in smart cards and price tags in shops for anti-theft measures. RFID tags can be passive or active, depending on whether or not they have a power supply. Passive tags lack a power source and receive the energy required for operation from the reader through induction. In the case of an active tag, a power source such as a battery is required, providing it with sufficient range to cover greater distances than passive tags. Passive tags work from a range of a few centimetres whereas active tags can work over a distance of tens of metres. Near Field Communication (NFC) is a technology based on RFID with the largest difference being the ability of a device to function both as a tag and as a reader [NFC]. NFC is currently used in some prototype mobile phones, enabling NFC tags to be read by touch with a mobile phone.

Recent developments in wireless technologies have focused on Ultra-Wideband (UWB), which is defined as a technology that uses a bandwidth of at least 500 MHz or at least 20 % of the centre frequency [Kolic04]. Traditional radio networks have transmitted data as long messages over a narrow channel but UWB uses extremely short wide-band pulses. These pulses typically last nanoseconds and the bandwidth can be several GHz (as shown in fig. 6.4). Thus the power of the transmission is rather large but it is spread across such a wide spectrum that it does not disturb traditional RF channels. UWB radios offer very high data rates with good privacy and compatibility, unfortunately a wideband transmitter (or several transmitters in close proximity) can cause disturbance in nearby equipment. UWB is also very resistant to multipath distortion (a situation where the signal bounces around and takes many different paths to the receiver) and stealthy (UWB transmissions can appear as background radiation). High data rate UWB is predicted for use in wireless monitors, wireless USB and other short-range applications.

Inductive data transfer is another way of communicating wirelessly using low power and over relatively short distances. Whereas RF communication is accomplished with radio waves that propagate through free space, inductive communication is based on two magnetically coupled coils (tuned to resonate at a specific frequency) that communicate in the near field. The receiving coil can sense variations in the magnetic field caused by the transmitting coil and data can thus be transmitted [Wang07]. Compared to traditional RF communication, inductive links are much more secure as the coils have to be closely matched and the signal is propagated only in the near field around the transmitter and not widely distributed like RF. Furthermore the required energy is lower and there are no problems

with interference or overcrowded frequencies. A limiting factor, however is the rather short practical range, usually limited to less than one metre as the fall in magnetic field strength is inversely proportional to the distance cubed. Inductive links are often used in body area networks [Tieranta05], RFID and wireless energy transfer.

Table 6.3 Comparison between wireless network types

Network	Frequency	Max. data rate	Power Consumption	Range	Cost
Bluetooth	2.4 GHz	1 Mbit/s	>100 mW	10..100 m	low
ZigBee	868 MHz, 2.4 GHz	250 kbit/s	>50 mW	200 m	very low
WiFi 802.11g	2.4 GHz	56 Mbit/s	< 1 W	25..600 m	moderate
GSM/EDGE/ UMTS	900/1800 MHz	9.6 kbit/s..2 Mbit/s	~1 W	several kilo- metres	moderate
UWB 802.15.3a	UWB	480 Mbit/s	< 100 mW	3..10 m	cheap
ANT	2.4 GHz	10 kbit/s	~1 mW	30 m	very cheap
Z-Wave	868 MHz	9.6 kbit/s	~25 mW	30 m	cheap

6.4 Network Functionality and Topology

The properties of smart home networks can be divided into two main categories according to their functionality and topology. Topology is related to the physical way in which devices are connected to each other and thus it has a bearing on reliability, complexity, cost and performance. Functionality, on the other hand, relates to how different functions are divided among networked devices and in which way they share resources. Precise classification is difficult because there are numerous ways to implement networks and software, the line between two different categories being very fine.

A centralised network (for example a star topology) relies on a central node for all its functions. All devices function through the central node, and connections to other networks and remote networks also go through this node. Remote nodes can be sensors, actuators, network adapters or user interfaces and the central node, for example, a PC. This topology greatly reduces the complexity required by remote nodes, communication networks and protocols, while the central node must have relatively fast processors and networks in order to process all information without additional delays. A drawback, however, is that a centralised network is totally reliant on the functionality and reliability of the central node. If this node fails the network can stop functioning. All smart home networks created at TUT have currently been of this type, mainly due to the expandability of PCs and ease of expansion.

Another choice is to not have a central node, which means that devices can be connected to each other in any way. Wired networks can be connected as a ring, through hubs or di-

rectly between devices: in the case of a wireless network each node can be capable of communicating with its neighbour nodes. In the former case there is always a path from one node to any other node in the network, but in a wireless network there can be devices that are out of range of a particular node. In practice this requires the network to support multi-hop networking, in which messages travel through other nodes hopping from one node to another until they reach their destination. Nodes are required to create a map of nearby nodes and even if a single node is not directly connected to a node it wants to communicate with, it is still possible to relay a message through other nodes. Further complexity is added by the possibility of ad-hoc networking, i.e. a spontaneous network that is formed by wireless devices in a place where there is no existing network infrastructure. An ad-hoc network can be formed between only two devices (point-to-point) or between multiple devices, either static or mobile.

In a centralised network functionality is also usually concentrated in the centre node. In a distributed network functionality and resources are scattered throughout the network, and any node can take over if another node fails. This type of network is much more fault-tolerant than a centralised network and it will continue to function as long as a communication path exists between nodes. However a distributed network vastly increases the complexity of devices and protocols because each node has to keep a record of nearby nodes (routing tables), their capabilities and location. Each device must also be able to identify itself to anyone on request, in order for the network to know what devices are present and what functions they offer. User interfaces can connect directly to any node (also possible in centralised networks in a limited fashion if service advertisements are not implemented), and they can communicate directly with a node or request a command to be sent elsewhere in the network. In practice, distributed networks require the use of some form of ad-hoc networking, which allows nodes to freely join and leave the network without the need for further reconfiguration.

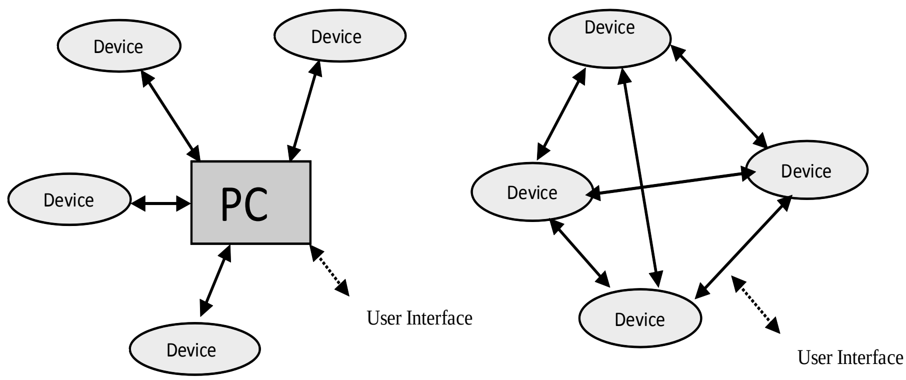

Figure 6.5 Centralised vs. distributed network topologies.

6.5 Home Gateways

A home gateway (or residential gateway) is a device that connects various home networks together and/or to the Internet, while offering diagnostics, remote control facilities and user interfaces [Valtchev02]. Since home networks can consist of many different kinds of networks and have incompatible physical connectors and protocols, a gateway can be used for connecting all these together. Home gateways are often based on standard PC hardware and thus possess sufficient capabilities to run software that enables them to do other things as well. For example, it can offer users a way to control the home from a remote location and a third party can perform diagnostics and maintenance tasks on the home from their offices.

Home gateways can be divided into two groups according to their function: physical gateways and service gateways. A service gateway connects functional software blocks (services) together and through them provides different kinds of services to devices in the home network, such as service discovery, content sharing and remote management. A popular platform for implementing service gateways is OSGi [OSGi]. A physical gateway is a simpler device, as it is more concerned about physical connections, routing and firewalling. A physical gateway thus connects many kinds of networks together, streams media and connects the home to the Internet.

In the early 2000s, as the Internet boom was gathering momentum, there were several home gateways being launched by large electronics manufacturers. These were typically shoebox-sized embedded computers running a customised Linux operating system, communication to the outside world was via DSL, cable modem or dial-up networking. Digital television was also being introduced throughout Europe and interactive services, such as web TV, were services that were to be offered through a digital set-top box. This box could also function as a home gateway, according to some forecasts, as it already contained necessary hardware and connections. From Finnish companies the most notable product announcements came from Nokia (Nokia Home Gateway) and Patria (Patria Ailonet). However, these products vanished completely only to reappear recently (for example the reincarnation of the Nokia Home Gateway) in an improved and different form [Nokia08_2].

Figure 6.6 Patria Ailon home gateway. Photo: Patria.

The current view of home gateways has changed slightly and they now becoming a convergence point for media, networks and communications instead [Saito00]. Households contain digital cameras, wireless devices such as laptops and PDAs, HDTVs, MP3 players and high-speed Internet connections that all can work together with the help of a media gateway. A PC can act as a gateway, but it would require installation of many kinds of software. A new wave of home entertainment electronics has brought with it compliance with DLNA (Digital Living Network Alliance) [DLNA], which allows devices to play media from other devices, share network resources, access UIs etc. DLNA is derived from a subsection of the UPnP [UPnP] standard and the list of compliant devices grows each day, with devices such as flat-screen TVs, Playstation 3 game console, printers and mobile phones being the most popular. In the near future this kind of interoperability might actually form a good base for a home control system, allowing information and UIs to be brought to any compliant device and network properties to be set up automatically.

One challenging issue with home networking is the complexity of setting up and maintaining the networked devices. Current network technologies can be rather difficult for novice users to comprehend, and setting up IP addresses, gateways, WLAN encryption and firewall rules are understandably complex matters. The ICEbox [Yang08] is a home gateway that attempts to make setting up home networks easier. In addition to lower level network tasks (e.g. automatic IP addressing), it also performs certain low level (encryption, physical link layer), higher level (file and resource sharing) functions, device monitoring and discovery. The ICEbox itself is a small PC-based information panel equipped with an infrared port, a touch screen and a key lock. The screen is used for controlling devices and making actions, infrared is used for registering and setting up new devices and the key lock for restricting physical access to the box. When a new device is introduced to the home network it is first brought (physically) to the ICEbox, during which services and other data are exchanged over the infrared link. The device then receives network settings and is set up for the current home network.

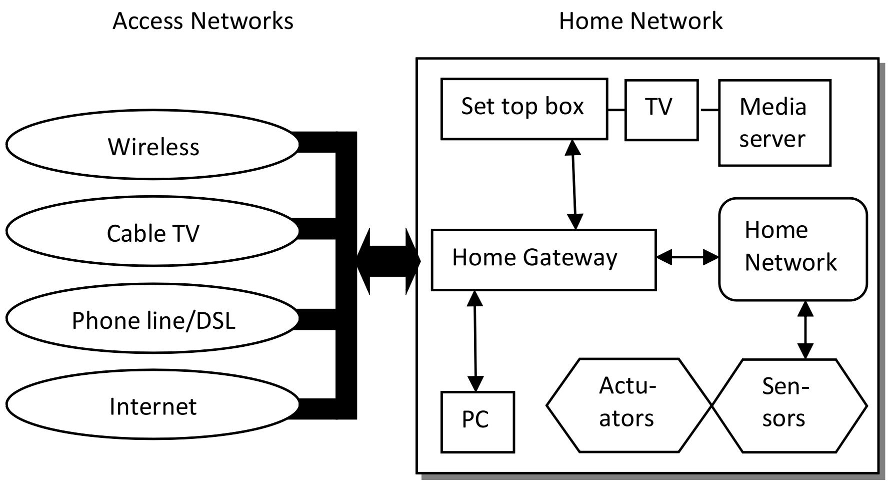

Figure 6.7 Block diagram of connections to a home gateway.

6.6 Sensors, Measurements, Detection

Sensors are primary sources for information in a smart space, indicating actions, movement and conditions both inside and outside. Sensors can be either static (fixed installation in the space), or mobile (worn or carried by the users), they can be integrated into structures or be part of a device. Sensor technology and integration has made huge advances in the last few decades and a multitude of integrated sensor modules are available today. The issues to be decided now are the kinds of sensors that are useful for smart home applications, where they should be installed and how the measurement data will be used.

6.6.1 Environmental Sensors

Temperature, humidity and light level sensors are useful for measuring local or remote conditions that are very relevant to comfort, well-being and health. By installing sensors in critical or interesting places it is possible to obtain even more detailed information. These kinds of sensors are typically very cheap and installing them into multiple locations is restricted only by the amount of manual labour involved. For example, temperature sensors in the refrigerator, on the balcony and near the kitchen stove could provide the system with contextual information on what people are doing in the home. Humidity and air quality sensors reflect the atmosphere in the home, and they can be used to indicate possible needs for ventilation or air conditioning. Light level sensors can indicate the lack or need of lighting or measure the amount of ambient light.

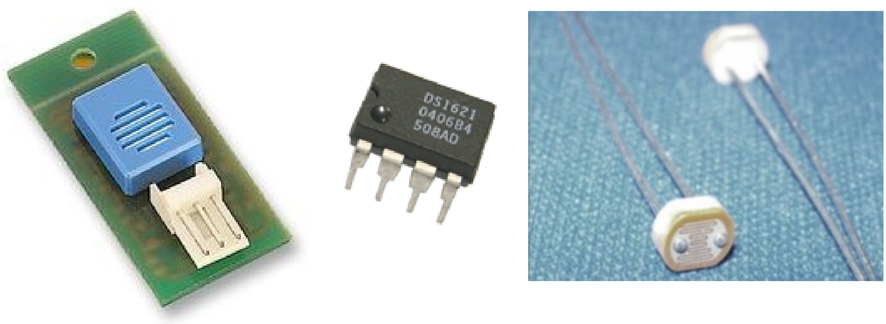

Figure 6.8 Environmental sensors used in the Smart Home, showing a humidity sensor (left), temperature sensor (middle) and light sensor (right).

6.6.2 Location Sensors

Sensors used for locating people, such as passive infrared (PIR), pressure sensitive switches, capacitive strips, Doppler radar, etc. are used to obtain an accurate image of where people are moving inside the space. Some of these are passive (i.e. do not actively transmit anything) and thus require no active components or worn equipment whereas active sensors can require transmitter/receiver pairs or similar equipment. Location information can

be used to control lighting, gather contextual information, for security measures and for learning people's daily routines. Unobtrusiveness is an important factor, as users might feel uncomfortable seeing that their movements are being watched or monitored in some way. Cameras, wearable locator equipment or similar technologies constantly remind people that they are under scrutiny, albeit only by a computer or software. Locating people is also only one part of the problem, tracking, identifying and coping with multiple user makes the challenges greater.

Floor sensors, usually installed under carpets, floor tiles or inside the floor structure usually require complex installation and cabling, making them too expensive or cumbersome to install. Thus it makes most sense to install them during the building phase. Floor sensors only work in locations where they are installed, if the apartment is not fully covered there will naturally be blind spots that have to be covered with other kinds of sensors instead. Floor sensors can be made using mechanical switches [Koskinen03] (first prototypes in the Smart Home), capacitive means using conductive tiles [Valtonen09] (currently implemented in the Smart Home) or other sensor film material, such as EMFi [EMFi] (used in the Living Room).

Passive infrared sensors detect changes in ambient infrared radiation created by movement and do not indicate whether they detect a single person or several persons or their exact location. Thus they are suitable only for detecting whether someone is moving in the vicinity or not. However they are cheap and easy to install in many locations, and currently they are mostly used for automatic lighting control in areas such as hallways and yards.

Active sensors, such as those using radar [Zakrzewski05] or ultrasound [Mäkelä08], transmit signals into the space and measure the strength of reflected signals (from objects or people in the space). Reflected signal levels can be quite low and signal processing is required in order to detect people or movement in the space and some kind of scanning is also required if a larger area is to be monitored. Ultrasound sensors are commonly used in burglar alarms and in medical applications.

Video cameras are also a viable alternative since standard webcams and miniature video cameras have become cheap enough to be placed anywhere. By processing the video signal it is possible to detect people and movement in the space, but this requires even more processing power and it is heavily dependent on ambient lighting and similar conditions. However a properly set up camera system could optimally identify users, gestures, movement and other actions.

Other novel methods have also been researched, ranging from powerline positioning (the system uses tone generators that transmit a signal into the powerlines and tags that locate these signals) to monitoring pressure changes in HVAC systems when people move about or doors are closed [Patel08].

Another use of location information is related to devices themselves; there are situations where the location of the device is important, even if it is not mobile or moveable. Context-aware applications, for example, would largely benefit from devices that are able to identify their own location [Hightower06]. This information is especially important when de-

vices can move around the space, be relocated or removed. However, obtaining this information can be difficult as very few devices contain technology for this purpose. Most current positioning hardware is built around GPS receivers, but these are not usable inside buildings or in dense urban surroundings. One alternative is to create a radio network that can estimate the location of each node by sending out signals to nearby nodes and calculating the relative distance from these using Received Signal Strength Indication (RSSI) [Lorincz06]. This would yield an approximate, relative location which might be sufficient for most applications. Another alternative is to search for nearby devices (whose location is known) and attempt to establish a position relative to these.

Table 6.4 Comparison between different location technologies.

Sensor	Price	Accuracy	Processing requirement	Other
PIR	very cheap	~10 m	low	detects only movement
Video camera	moderate	centimetres...metres	high	depends on ambient conditions
Radar	expensive	low...very high	high	low...very high
Floor sensors	cheap	~1 cm	moderate	expensive to install
GPS	moderate	~10 m	low	does not work indoors
RSSI	free	~10 m	low	depends heavily on ambient conditions

6.6.3 Biosensors

Sensors for monitoring the space's inhabitants present the biggest challenge. They should be as unobtrusive as possible, without interfering in users' lives or requiring extra attention. Wearable biosensors (e.g. electrocardiogram or blood pressure) have not been considered in this research, but other ways of measuring and monitoring people have been investigated. Sensors mentioned in the previous paragraph can also be used for this purpose. Heart rate, for example, can be monitored using Doppler radar [Zakrzewski05], with capacitive or pressure sensitive sensor films installed under the floor or in the bed [EMFi]. Body temperature can be sensed with infrared cameras, weight with pressure sensitive sensors, and height with capacitive sensors [Valtonen09] or by visual means (e.g. using video cameras). Movement and activity can also be detected with accelerometers and angular velocity sensors, installed in various locations, such as UIs, furniture and small, portable devices. These can indicate whether or not a device has been used, or the kinds of movements the user has performed. Biometric measurements could give useful information to the home system on the inhabitants' state of mind, alertness and activities (sleeping, tired, stressed etc.). Also, when the biometric data is sent to a health centre, patients could be monitored at home without having to stay in hospital. This would facilitate earlier recovery and help reduce the queues at hospitals [UUTE].

6.6.4 Sensor Data Processing

Most sensors transmit data at regular intervals and require very little bandwidth, transmitting a few bytes at a time. A sensor places little demand on the network itself, the most important criteria are dependability and robustness. Some sensors, however, transmit data continuously and require large amounts of processing before sending the data to the rest of the system. A floor sensor unit, for example, would have to constantly monitor sensor modules, compare readings to previous measurements and attempt to detect movement across the floor. If the sensor module itself lacks the required processing power, it has to send all measurement data to another processing unit, which requires considerably more bandwidth and lower latency than a simple sensor network would have. Using video cameras as sensors also presents challenges for signal processing, as image data requires a lot of processing power and efficient algorithms to be useful in smart home applications. Currently microcontrollers, smaller processors and digital signal processors are already able to perform complex processing on the sensor board itself, reducing the load on the server. However, there are often situations where changes or adjustments in the processing algorithms are required, and in these cases it is usually much easier to update all software on the server instead of upgrading each sensor separately.

Useful data can also be collected from other appliances and devices in the home. Many already come with internal temperature and other similar sensors for their own purposes, and if this information could be transmitted and shared with the home network it could also provide valuable information. Even a small piece of information, such as on/off data, can be very useful when contextual information is being gathered. This notion is also shared by Robert Metcalfe (one of the people behind the development of the Ethernet network standard) who wrote a law that states that "the value of a telecommunications network is proportional to the square of the number of connected users of the system" [Shapiro99].

The type of data received from the sensor can also vary greatly depending on the sensor type. Simpler forms of data can be on/off information from a switch or a pure numerical value that is usually obtained from an A/D conversion. A brightness value of 223 or a floor sensor capacitance reading of 42441 do not mean anything as such without a reference scale or threshold value. Analogue values are difficult to convert to digital discrete information; for example, if a temperature threshold is set to +23 °C then 22.9 would be considered cold and 23.1 warm, even if a person could not detect this difference in practice. For such analogue quantities a fuzzy representation [Valtonen07] is much more suitable, as it is closer to the way humans perceive and describe quantities. In this case, 15 °C would be rather cool, 22.9 °C warm and 32 °C rather hot. Some sensors, on the other hand, only report on/off type binary information, which is relatively simple to use directly in user interfaces, for example. A magnetic door sensor can detect if the door is open or closed, a passive infrared sensor can detect whether people are present or not and so on.

Sensors that measure continuously or periodically gather large amounts of data in a short while. This data can be analysed to detect patterns, repeated events or other information of importance. Pattern recognition is thus an important factor in machine learning and data categorisation. Pattern recognition is used in speech processing, medical applications and image analysis. Data collected from all sensors in a smart home can rapidly use consider-

able amounts of memory capacity amounting to thousands of megabytes. When such amounts of data are being processed on a computer, transformation to another form might be required to make processing easier and faster. A paper by M. Galushka [Galushka06] describes methods of transforming and analysing data recorded from smart environments. This approach is important especially with context-aware applications, where data is constantly being collected, analysed and stored.

6.7 Sensor Networks

The concept of sensor networks usually covers large concentrations of sensors, distributed over a specific area. This might be a factory building with environmental or process-related sensors [Connolly05], a forest with humidity and temperature sensors mounted onto trees or a glacier with GPS modules that measure its movements [Martinez05]. Sensor networks such as TUT wireless sensor network [TUTWSN] could also be used for domestic applications. In general, sensor networks utilise small, battery-powered sensor modules with some processing power, an energy module and a radio transceiver to allow them to communicate with each other or a main network node. In order to keep power requirements and complexity low, the range of the transceiver might not be more than ten metres. As described earlier, in order to cover greater ground, sensor nodes can send messages through each other, with the message hopping from one node to another until it arrives at its destination. This multi-hop network topology enables network nodes to communicate with each other without the need for a rigid network infrastructure, either wired or wireless. Nodes can communicate directly with each other or with a remote node using other nodes as relays. The network protocol becomes rather complicated, as it has to be able to find an optimal route for the message, taking into account the complex and non-fixed structure of the ad-hoc wireless network. In addition, since nodes are fairly independent and there is no central node that governs traffic, it has to be possible to program nodes on-the-fly. Otherwise it would only be possible to adjust certain parameters, and if the application or environmental factors suddenly change, a simple adjustment in the node's programming would not suffice.

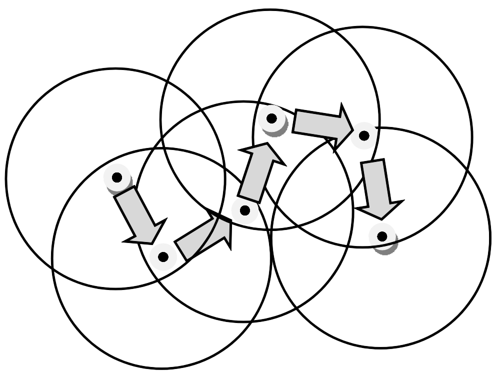

Figure 6.9 Illustration of a message hopping through nodes to reach its destination.

Current sensor network modules are still macroscopic in size but the technology is predicted to shrink significantly, making millimetre-size modules possible. Smart Dust [Pister99] is one possible outcome of such miniature sensor networks, making it possible to create affordable, flexible networks with dense sensor coverage. Sensors could be deployed rapidly by dropping them from an aircraft or shot on site in a mortar shell. Smart Dust sensors are essentially Micro-Electro-Mechanical Systems [MEMS] that, in addition to miniature electronics, also have mechanical functionality. Smart Dust sensors are too small to contain batteries, but instead they can harvest their energy from the environment, for example from ambient heat, movement or light. Possible uses for Smart Dust include forest fire detection, environmental or biological monitoring, military applications (e.g. surveillance) and healthcare (patient monitoring).

6.8 Actuators, Controllable Devices

Actuators perform the actual physical tasks in the home. Traditionally a home has very few (or none) networked actuators and most actions are performed manually. A garage door opener or ventilation fan might exist but there is no control network for these. In smart homes it is possible to install more controllable motors, servos and valves and connect these to the home network. Thus it becomes possible to control and monitor these from any UI in the home. Features that could prove useful to inhabitants include motorised blinds, dimmable lights, motorised windows and doors, controllable air-conditioning, and with the help of these it is possible to impact environmental conditions and physically affect the space. Home appliances and other electrical devices are more difficult or even impossible to control remotely, depending on the implementation and the functions of the particular device. Certain functions can be achieved by simply switching the power supply on or off, but for many modern electronic devices this might have complications due to resetting clocks or losing settings. Kitchen appliances rarely have any means of remote control or communication, and thus controlling them is also a challenge. On the other hand there is not a great need for this, since people have to be present for cooking activities in any case. For safety reasons, it is more practical to measure current consumption, temperatures and user presence and, in the event of a problem or accident, the gas or electricity could be cut off.

Home entertainment equipment usually has infrared remote controls or utilise manufacturers' own proprietary systems links, and for these reasons it can be difficult to integrate them into the home network. Infrared remote controls only work in one direction, and command sets usually vary a great deal from one manufacturer to another. Some devices have standard serial RS-232C ports and they accept a wide variety of commands, making it much easier to control them through a home network. However, the integration of audio-visual equipment could deliver additional functions and benefits to inhabitants, for example, by providing feedback, information or entertainment related to the user's contexts. Displays and TVs can function as graphical UIs or information panels, and audio systems can be used for delivering audio feedback to users. Further information can be gathered if the system can know what TV channel is being watched and how high the volume level is.

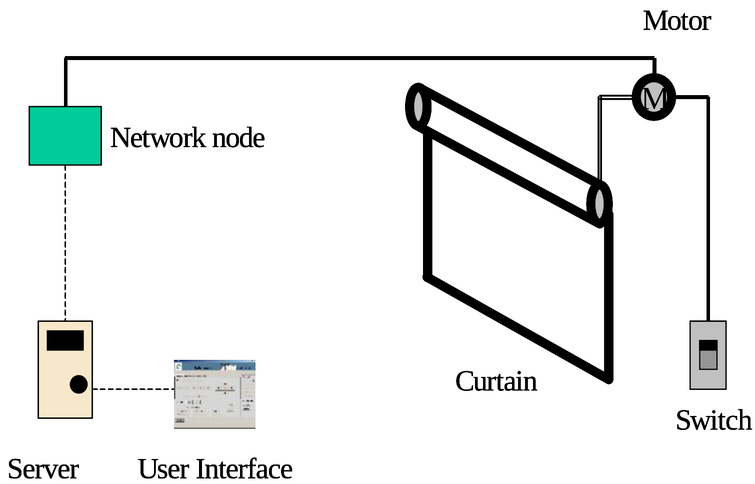

Figure 6.10 Components and connections of a typical smart home actuator, in this case a curtain controller.

6.9 Power Consumption

Power consumption is often a property that is not directly visible to the user, especially in the case of devices that use mains power supply. However as the number of devices grows and price of energy increases, consumption begins to become important. Since one of the objectives of smart home technology is to lower power consumption, it would be beneficial if smart devices themselves were also designed with maximum power savings in mind.

Batteries provide users with better mobility but they also impose practical limits for operating times. One problem is the race between battery, software and electronics manufacturers: if a faster processor is developed it is able to run software faster, which leads to software becoming more complicated and demanding with more functions and capabilities. Faster processors consume more power, and the advances that are made in battery technology are quickly overtaken by these growing power consumption figures [Starner03]. Increasing power consumption also causes problems as electronics miniaturisation advances: the smaller the physical size of a chip becomes, the harder it is to provide sufficient cooling for it. Conducting heat away from a physically small area is already a major problem with today's desktop processors, limiting maximum operating frequencies. Methods to avoid overheating include lowering the operating voltage of the processor and utilising parallel processor cores.

Largest energy savings can be achieved by using power saving and sleep states that controllers and ICs offer. If the software permits, the controller can enter a low-power state whenever possible. For example, the Atmega8L microcontroller's (which is used in many devices in the Smart Home) datasheet [Atmel] states these current consumption numbers:

Atmel Atmega8L @ 4 MHz, Supply voltage 3.0 V

- Active state : 5 mA
- Idle state: 2 mA
- Power-down mode, watchdog timer disabled : 2 µA

A popular sensor module, the telosB (introduced later in this chapter) states the following power saving modes:

TelosB mote, MSP430 MCU, powered by 2 x 1.5V AA batteries

- MCU on, Radio receiving 21.8...23 mA
- MCU on, Radio transmitting 19.5...21 mA
- MCU on, Radio off 1800...2400 µA
- MCU idle, Radio off 54.5...1200 µA
- MCU standby 5.1...21.0 µA

In wireless devices, power consumption is often a compromise between wake-up time, maximum range for the radio network and response time; if the processor is in very deep sleep it will take a relatively long time for it to wake up and become active again. If the radio is turned off it obviously cannot listen to any traffic, and therefore the device cannot send or receive anything. Further savings can be achieved by designing and optimising the schematic, power supply and with proper component selection. Reducing the clock frequency to a minimum helps in reducing the power consumption of the processor, and software optimisations can also help [Vuorela06]. For ultimate energy efficiency, energy harvesting, as explained earlier in this chapter, can theoretically make the device energy independent or at least requiring little external energy.

6.10 A Typical Smart Device

Devices in the Smart Home can be divided into three basic categories: sensors, actuators and input/output devices. Sensors perform measurements, actuators perform physical tasks and input/output devices are the interface between the user and the home control system. Common properties of these are that they are aware of their own state, they can send and accept commands from the rest of the system and they have a specific identity or network address. Thus they are able to receive commands, perform a task (e.g. measure, adjust) and report back to the network master. In order to do this, a smart device needs a microcontroller for processing, input and output connectors for controlling and communicating with external equipment (sensors, motors, LEDs), a power source and a communication link to the home network. The Department of Electronics has excellent facilities for electronics board design and prototyping, and thus it has been possible to implement new devices and modify existing ones.

Most devices have a standard connector that allows them to connect to each network (RS-232, wireless RF, Bluetooth). This standardised RJ-12 connector houses serial receive/transmit data lines, common ground and +5 V power supply. The device is designed to pro-

vide power (+5 V) for an external wireless data module (RF, Bluetooth) or a sensor board through the same RJ-12 connector. When the physical connector is standardised there is no need for reconfiguration if the network type has to be changed. A wired device can be changed to using wireless RF or Bluetooth, simply by removing the serial cable and attaching a wireless transceiver module into the connector instead. Addressing is implemented by mapping the physical port on the serial hub that it is plugged into to a hardware address (wired devices), or from the ID code on the wireless transceiver module (wireless RF devices).

As well as the serial port, additional communication interfaces or I/O - ports may be required to control external equipment, such as sensors and relays. Some devices also have a kind of a user interface to allow manual control, for example, with motorised blinds and projector screens, each which has pushbuttons for manual control. Sensors typically use I2C, RS-232 or SPI - buses.

Fig. 6.11 below shows the structure of a typical device in the Smart Home.

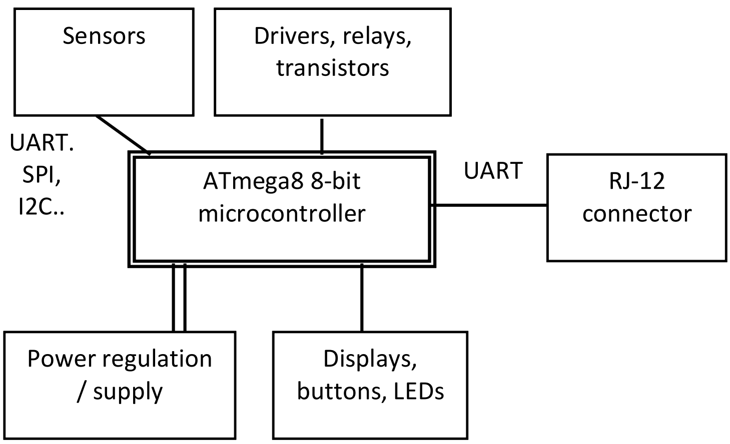

Figure 6.11 Block diagram of a typical smart home device.

Devices in smart home projects at TUT have undergone several years of development and evolution. The first device created, a flower pot monitor, used a simple 8-bit Atmel AT90S1200 microcontroller with 1 kB of flash memory. Programming was done using Assembly language and the components used were all through-hole mounted. A little later the programming language was changed from assembly to C, and as a consequence controllers with more memory were also required. Surface-mount components allowed circuit boards to be significantly smaller in size and more inconspicuous. More modular design techniques were used, and after the RJ-12 connector was standardised prototyping became much faster and easier. For example, the controller unit for the Smart Home window blinds was designed according to these specifications using an Atmel AT90S4433 controller with 4 kB flash memory. Blinds are controlled using six MOSFET transistors and the position of the blinds is read with the on-board ADC using potentiometers connected to the motor turning the blinds. After numerous follow-ups the next step was to concentrate on the func-

tionality of the network, adaptive software and service discovery protocols. Designing and implementing hardware takes some time, as is the case with writing software for every application. With the move towards a modular, standardised platform many steps can be avoided and prototyping time reduced. Mote sensor modules (described in more detail in the next section) offered these properties, and they represent a large part of the future hardware in the Smart Home.

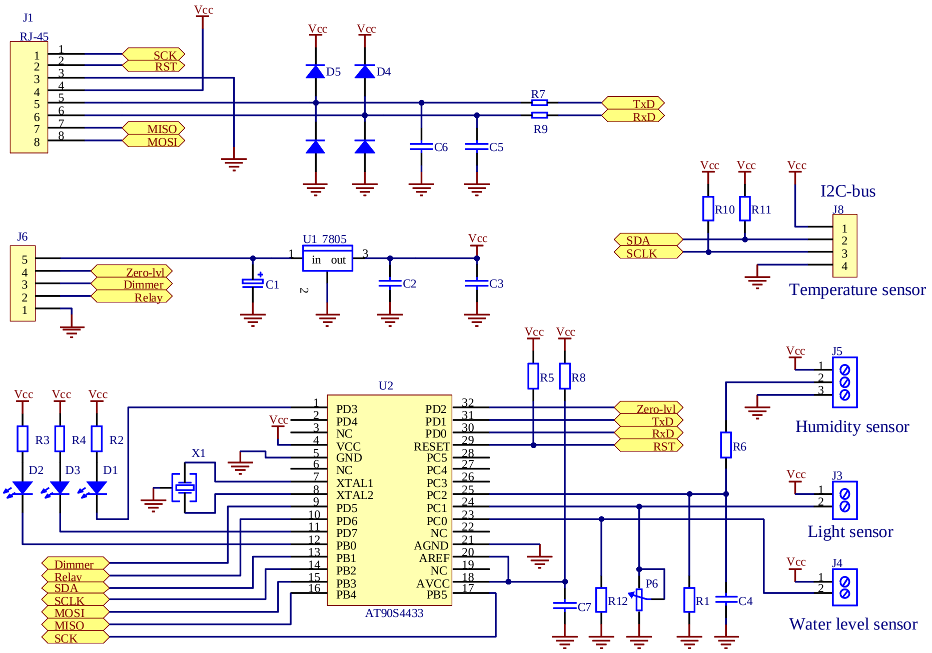

Figure 6.12 Schematic of the flower pot controller in the Smart Home.

6.11 Smart Sensor Nodes

Since many features and requirements of networked nodes in a smart home are quite similar, it makes sense to create a generic network node that can be used in multiple applications. These kinds of modules are available from many manufacturers and they typically contain a low-power microcontroller, wireless radio interface, some I/O connectors, flash memory, power regulation, a few built-in sensors and A/D converter. These modules can be used as sensor platforms (utilising built-in sensors), network interfaces to other equipment, actuator controllers or network relays. Ideally a node would be millimetre-sized and thus small and cheap enough to be used in vast quantities and distributed over a specific area. This “smart dust”, as mentioned before, could be used as a deployable sensor field, embedded into structures, etc. Practically, however, these modules are not size limited as the batteries that they use are large anyway. The rest of this chapter presents a few commercial sensor modules and their primary properties.

Berkeley mote

The mote platform, briefly introduced in Section 5.6.3, [moteIV] was developed by University of California, Berkeley, and has since been very popular for prototyping sensor networks around the world. The mote family consists of several different models (MICA, telosA/telosB, Imote, etc.) that vary in size, performance and abilities. Motes are commonly used in conjunction with the TinyOS operating system, allowing similar development environments regardless of hardware configuration. The technical implementation is different between types of motes, for example, CPUs used are Atmel's AtMega series or Texas Instruments' MSP430 series, sensors (accelerometers, light, temperature and humidity etc.) and RF transceiver (802.15.4 compliant, 868 MHz or 433 MHz proprietary radios).

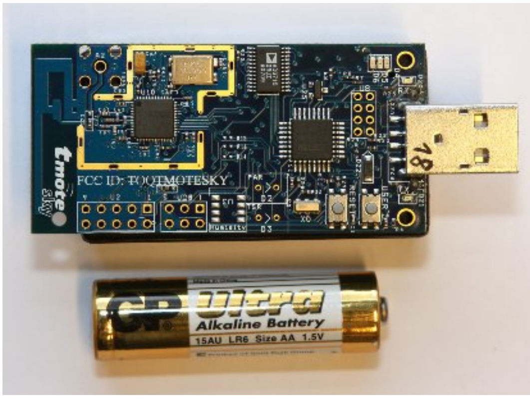

Figure 6.13 tmote SKY (also known as mote IV) module.

Scatterweb

Scatterweb [Scatterweb] is another solution for sensor networks, and a scatternode is the equivalent of the mote platform. It also uses the MSP430 microcontroller, an 868 MHz radio, an A/D converter and 512 kB EEPROM memory. The mainboard can be augmented with separate sensor and power supply modules if needed. Multiple scatternodes can form a multi-hop scatterweb network that is ideal for sensor networks or similar applications. Scatterweb is intended for use in sensor applications, energy management and structural health monitoring. The Scatterweb software also includes drivers for connecting nodes to other kinds of networks (e.g. Zigbee, KNX).

Figure 6.14 Scatternode.

Smart-Its

The Smart-Its project [Kasten01] is part of the European Disappearing Computer initiative and it aims to create small-scale embedded devices that can be embedded into everyday objects, enabling new kinds of sensing, computation and communication. Five prototype hardware platforms have been created using both PIC and Atmel microcontrollers, Bluetooth and 868 MHz radios, wired RS-232 and I2C communications. Smart-Its are able to collect data from their environment and share this with each other, creating a collective awareness.

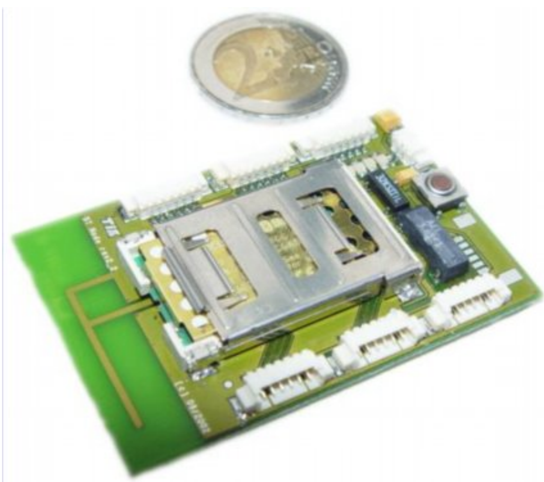

Figure 6.15 Smart-Its module board. Photo: ETH Zürich.

VTT Soapbox

The SoapBox (Sensing, Operating and Activating Peripheral Box) is another small platform for sensor networks, developed by VTT [Tuulari05]. As the name implies, the hotel soap bar-sized module consists of two modules stacked on top of each other, an antenna, battery and other circuitry. Sensors in the SoapBox module include acceleration, light, temperature, proximity (IR transmitter/receiver) and a magnetic sensor that also acts as an electric compass. The 868 MHz radio connects to a central server and the operational range varies between two and 80 metres, depending on the power level used. SoapBox sensors have been used as movement and attitude detectors in handheld user interfaces, for example, enabling navigation through the UI by tilting, turning and moving the screen.

Figure 6.16 VTT Soapbox module. Photo: VTT.

Sensinode

Sensinode is a company currently concentrating on creating small IP stacks for embedded devices, but they have also created network node modules (Sensinode nano and micro). The nanostack IP stack is written in C and designed to be usable in low power microcontroller applications. Sensinodes use 2.4 GHz IEEE 802.15.4 system-on-chip CC2430 radios for communication and they can be organised in different network topologies.

Figure 6.17 Sensinode evaluation kit. Photo: Sensinode.

Sun SPOT

Sun laboratories have created a Java-programmable sensor module, the Sun SPOT (Sun Small Programmable Object Technology) [Sunspot]. Compared to previously mentioned nodes the SPOT is more powerful and complex, as it requires more processing power and memory to run Java software. The core of a SPOT is a 32-bit ARM920T processor running at 180MHz, together with RAM and Flash memory. An auxiliary Atmega 88 microcontroller is reserved for further functions. Communication with other nodes is performed with an 802.15.4 - compliant RF transceiver and a USB connector. The internal rechargeable battery is sufficient for a running time of 3...7 hours of continuous usage; further extension of battery life can naturally be achieved by reducing the active time of the processor and using various sleep and power saving states. The SPOT board includes sensors for measuring acceleration, temperature and light. It is designed to be a flexible development platform that is capable of hosting many kinds of application modules.

Figure 6.18 Sun SPOT module. Photo: SUN Microsystems.

Table 6.5 shows a brief comparison between sensor nodes, listing their radios, processors, sensors and current consumption.

Table 6.5 Comparison between sensor nodes.

Sensor node	Radio	Current consumption	CPU	Integrated sensors
tmote	802.15.4	5.1 µA (sleep) 19.5 mA (active)	MSP430 @ 8MHz	Temperature, light, humidity
Scatternode	Chipcon 1020 @ 868 MHz	250 µA (standby) 250 mA (peak)	MSP430	Temperature, vibration, movement, light
Smart-its	Bluetooth / 868 MHz	< 3.7 mA (sleep) 67 mA (peak)	ATmega103L / PIC 16F876	N/A, available as external modules
Soapbox	868 MHz	< 6 mA	unknown	Acceleration, light, magnetism, proximity
Sensinode	802.15.4	unknown	Chipcon CC2431	Acceleration, light
SunSPOT	802.15.4	36 µA (sleep)	ARM920T	Temperature, light, acceleration

6.12 Discussion

The hardware presented in this chapter allows smart home designers to choose the most suitable components for their homes. Wireless networks allow freedom of placement and movement, while wired alternatives are more reliable, robust and faster. The inclusion of

a home gateway of some sort makes network selection easier, as gateways typically contain multiple network interfaces and are able to cope with many kinds of protocols. The gateway functionality does not have to be contained to a specific physical device, it can be distributed between home appliances or included in another kind of device. In order to sense the environment a smart home system needs sensors, and depending on what kinds of sensors are available the system can gather enormous amounts of data. For this reason it is important to choose the right kinds of sensors for an application, otherwise the amount of sensor data can become overwhelming or the nature of the data can be irrelevant for the application in question. For example, context aware applications would benefit greatly from sensors that monitor the users and their activities whereas an application concentrating on optimising energy consumption would mainly require current consumption and environmental sensors.

A smart home would not be very useful if there was nothing for users to control and use. Actuators, home appliances and mobile devices provide users with means of physically affecting the environment and controlling their homes. Legacy home appliances and other non-controllable devices can cause problems as it might not be possible to monitor or control them in any way, creating a “black hole” in the home infrastructure where no information is available. Power supply and power consumption are other issues, which are a concern not only for economical reasons but also for practical reasons: cables, transformers and batteries are an unwanted sight in homes, and it is not uncommon to see a great number of entangled power cables behind television stands and computers. Most devices cannot use mains power directly and thus require a transformer or power converter, which adds to their power consumption and can seem as an unnecessary step for users as external transformer units require their own space around power outlets. Furthermore, as mobile devices mostly are battery powered they are charged only momentarily with the power supply running idle for the rest of the time, it can seem to users as a waste of energy. Indeed various voltage converters, power supplies and battery chargers add to the energy consumption of the device, and until a more efficient way of providing power to devices is invented the only way to remedy this is by creating more efficient power supplies and batteries. Wireless power transfer could eliminate the need for power cables, but it will probably not increase energy efficiency in any way.

Chapter 3.2.1 presented five requirements for future Ambient Intelligence technology [ISTAG01], with the first requirement being unobtrusive hardware. This would imply small, wireless sensor and network nodes that are able to perform measurements and tasks without unnecessarily disturbing the user. The second (a seamless communications infrastructure) and third (dynamic and massively distributed device networks) requirements require a flexible network infrastructure and service discovery protocols that are able to connect devices to the home network without requiring much or any input from the user. The fourth requirement, natural feeling human interfaces, benefits from embedded sensors and unique and natural user interfaces. The final requirement, dependability and security, focuses more on the reliability of the system and the security of the users. Reliability is dependent on both hardware and software, whereas security is more related to the implementation and features of the system as a whole.

Further IST requirements for AmI [ISTAG03], such as new materials, would mainly benefit UIs and sensors, as they would enable new sensor materials and innovative UIs to be constructed. MEMS, on the other hand, would make it possible to design microscopic actuators and devices that will open up new worlds in biotechnology, high frequency communications and microsensors. Tiny robots, implantable technology and extremely small sensors are examples of such applications.

6.13 Summary

As is evident from this chapter, there are numerous choices available for hardware platforms, networks and protocols for smart home designs, and choosing the most suitable one can seem a major task. Most smart home devices however do not require any specialised hardware, and are thus not limited or bound to any specific platform or architecture. It is the software and interfaces that are more important factors when compatibility and standardisation are being considered. In the future new materials and technologies can drastically change the way we use and interact with devices, bringing the future smart home one step closer.

7. Software Architecture

While the most visible features of smart homes are appliances, sensors and devices it is the underlying software architecture that actually defines the functions, intelligence and usefulness of the smart home. Depending on the network type (as previously described, centralised or distributed), the appliances and sensors typically contain only simple software that is designed to perform a predefined function, communicate and report its status to the network. More complicated functions are performed by the rest of the home systems, through computers or home gateways running sophisticated adaptive algorithms, middleware, and server software.

Home control software can contain several functions, practically limited only by the imagination. Normally there are at least user profiles, pre-set modes (home, away, at work etc.), timer settings and master controls. If the computer running the software is sufficiently capable, it can also function as a home media server or gateway, streaming video and serving files to other devices in the home. Instead of a large, noisy PC it is also possible to use a more discrete embedded control unit that is dedicated to home control.

When server software is being designed there are many design factors and options that affect the functionality, modularity and flexibility of the system. In research environments this step is often skipped and the end result becomes a myriad of separate software that run on a standard PC. Instead a modular, expandable core would provide an easier upgrade path and room for future improvements as well as connectivity to other software components, either running locally on the same machine or in a remote location. The choice of programming language can also affect the flexibility of the software system, for example, using a platform-independent programming language such as Java would allow the software to be run on several kinds of platforms.

This chapter presents design issues with smart home control software, various kinds of middleware implementations and embedded software used in smart home devices. Protocols used in smart home projects at TUT are also presented.

7.1 Centralised vs. Distributed Intelligence

The smart home infrastructure can either rely on a central “master” server that manages all connections, devices, artificial intelligence and resources or these functions can be scattered all around the network (as the ubiquitous computing definition suggests). As explained in the previous chapter, a centralised version has obvious weaknesses that relate to the reliability of a single computer, software and network stability, but on the other hand it also reduces the workload on all other the network nodes. Networks and protocols and also software can be simpler, since all relevant information is stored on the central node. Nodes may communicate directly with each other, but due to the simplistic nature of the setup the usefulness might be rather limited (they might require assistance from the central node).

The important element, however, is the artificial intelligence itself; how it reacts to new situations, what kind of functionality it offers and how expandable it is. Artificial intelligence in this case is a piece of software that monitors the situation in the smart home, gathers measurement and activity data and makes decisions based on the knowledge that it has at that particular moment. The most basic form of home control software would be simple home automation, which at most would have some user-configurable settings (timers, group controls and preset modes). However this would not fulfil the requirements for a smart home, so more functionality is required. A more advanced version would allow users to program more complex settings, and possibly incorporate some kind of "if-then-else" type logic. For example, lights could be turned off in the night if nobody has been detected in the living room during the last 30 minutes. This kind of programming would already allow reasonable flexibility and many smart home functions, but it takes time if users have to manually program all possible variables into the computer. There would also be many cases where this kind of reasoning would fail and produce unwanted results.

Adaptive home software would remove the programming burden from the user's shoulders. A software capable of learning would adapt to the users needs, and if a wrong action is taken it is possible for users to take counter measures and thus teach the system what the desired action would have been. Adaptivity is also required for UIs and in decision-making, since the layout and type of home devices can continuously change depending on what people carry with them. Context awareness will further assist the system with making decisions and processing data, as it will provide the system with more information about what users are doing.

7.2 Middleware

Middleware is the media that connects devices, networks, software and services together in a smart environment. Middleware is defined as connectivity software that allows software components and services to interact across a network [Bernstein96]. Middleware is required in order to have distributed computing services and heterogeneous platforms working together and it allows applications to be located throughout the network, increasing reliability. Figure 7.1 below illustrates how middleware is situated between applications and other platforms.

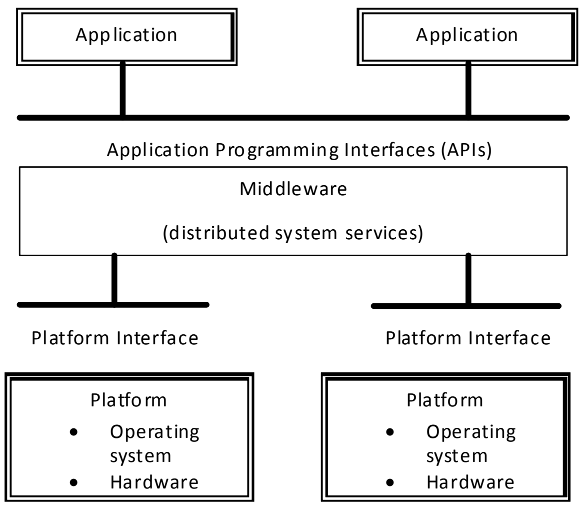

Figure 7.1 Example of how middleware can be implemented [Bernstein96].

In a home environment the middleware would essentially be a software package running on a home server. A dedicated home gateway or a similar device could also function as a home server, but recently the future of such, poorly expandable and upgradeable machines has become uncertain. Game consoles, home theatre PCs and set-top boxes are constantly gaining popularity and new features and they may soon deliver similar functionality at an affordable price. However, a dedicated control unit would be preferable as it would be more reliable and tailored for this specific application (compared to a PC with random software modules running at the same time), but problems arise when updates or changes to the program have to be made. Interfacing with a home control box would probably require access through another terminal or similar complicated tasks. When devices are added, services or preferences are modified so that changes to the server probably would have to be made, either by the user or automatically by the system.

A home server with appropriate middleware could offer services such as timers, logging functions, preset modes, distributed UIs and group controls. The middleware also makes controlling the home more user-friendly, allowing users to make higher level decisions instead of worrying about network standards, software packages and driver versions [Valtchev02].

The middleware can also be responsible for creating user interfaces, and depending on the UI, this can be a fairly demanding task. Dynamic UIs that reconfigure themselves according to what devices and services currently are available would require a middleware with extensive knowledge of where devices are and what features they offer. Simpler, static UIs only require up-to-date information about the states of each device. Figure 7.2 shows the connections of a home server with middleware, different kinds of networks and devices, and how they connect to middleware components.

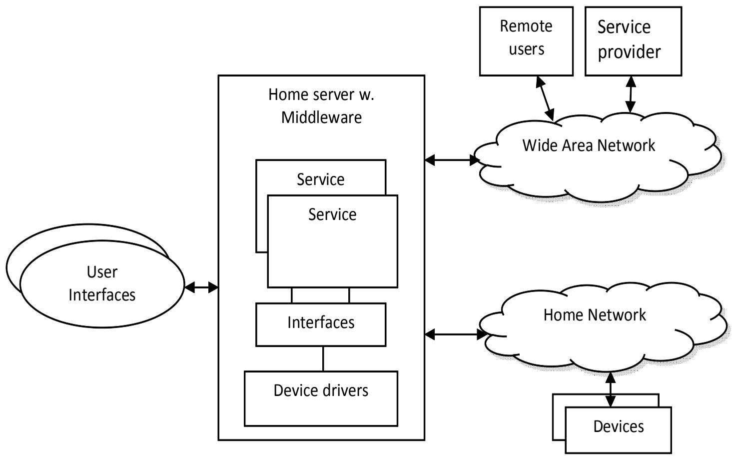

Figure 7.2 Connections of a server running middleware software.

7.2.1 OSGi - Open Services Gateway Initiative

The OSGi Alliance [OSGi] was formed in 1999 to promote open standards for a middleware Java framework. The OSGi platform was designed to make it easier to design, maintain and deploy applications in networked computer environments. The OSGi alliance consists of developers and technology innovators, and the platform has been a topic of many smart environment middleware research projects. For example, Tao Gu et al. used OSGi to create an environment for rapid smart home application prototyping [Gu04].

The OSGi specifications include APIs, services and layers but the most important features are component models and applications that can be started, stopped and installed without requiring a reboot. This makes it is easy for the application to download new drivers when new devices are added, and remove them when they are no longer needed. The original specifications were designed with service gateways in mind, but lately the standard has also spread to the automotive, automation and entertainment industries. However, the list of certified products includes only six items to date.

7.2.2 COBA - Connected Open Building Automation

COBA [COBA] is a standardised operating system developed for building automation, which provides a standard interface to all building management systems. Development started in 2000 together with telecom, IT and construction industries and the first applications emerged a few years later. The goal was to create a worldwide open de-facto standard for a “building operating system”, which would give users easy and secure access to the functionality of a smart environment using various UIs. COBA is directed mainly towards building management, security and electronic real estate control, and its focus has largely been on large buildings, factories and offices rather than homes. However, the situation has changed during the last few years and now COBA is also making a move towards homes.

COBA uses definitions of the building, its technical systems and proposed user roles to create a COBA- compliant conceptual model of the building. COBA definitions include open interfaces to all systems related to building management as well as modelling of the physical building, different spaces, devices, systems and users. Using control groups and information points, the system can obtain information and control building automation, lighting control, consumption management, access control and security systems.

Current COBA-compliant hardware includes security cameras, access control systems, fire alarms and water/heat regulators.

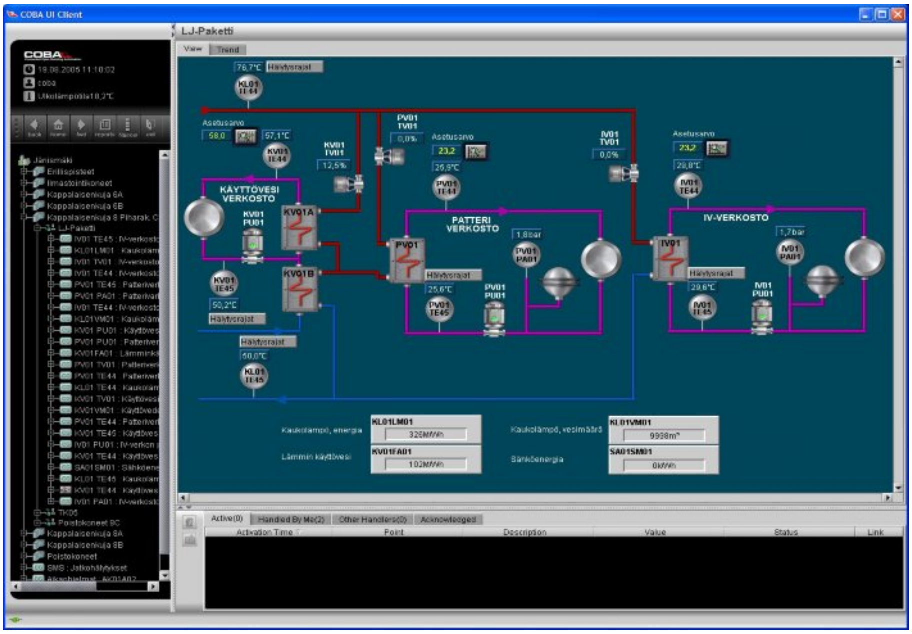

Figure 7.3 Screenshot of a COBA heating system control UI. Photo: Lonix.

7.3 Service Discovery

The point of a service discovery feature is to provide clients with a method for locating services that they require and devices to advertise the features that they are able to provide [Sundramoorthy03]. In other words, it allows providers to advertise themselves and services to find resources that they need. For example, a user interface wanting a temperature reading from the living room could initiate a search for temperature sensors in that area, select an appropriate device and request a temperature measurement from it. This kind of implementation also makes the network more robust and fault tolerant since it is possible to discover non-functional devices and perform a search for replacements or best possible alternatives. In the previous example, if the temperature sensor in the living room was not functional it would be possible to search for any devices that are able to measure temperature and use their readings instead. A network using service discovery is also useful for

sharing resources, as data and processing power can be distributed throughout the network to other devices, increasing performance and redundancy. Network traffic can also be reduced by relocating data in the places where it is most likely to be needed.

In a smart home scenario, service discovery is essential as the network usually is a myriad of heterogeneous devices that can appear and disappear at any time. The ability to communicate directly with another device, remotely control it or replace it with another similar device can also be very useful. There are several service discovery protocols available, though they are not yet standard for smart home systems due to incompatibility and resource requirements. Listed below are a few common service discovery protocols.

UPnP, developed by Microsoft [UPnP], uses multicast technologies over an IP network to broadcast service information and XML documents providing service descriptions. The goal of UPnP is to provide zero-configuration networking and remote control of devices and it has thus found its way into home entertainment devices and network hardware. The DLNA (Digital Living Network Alliance) [DLNA] alliance also uses UPnP to share media through the home network, for example, in the case of amplifiers, TVs and game consoles, where it is already in use. Due to XML parsing and heavy use of multicast, UPnP consumes resources rather heavily and thus is not a viable choice for smaller low-power devices.

Another alternative protocol, Jini [Jini], was designed to transfer computing away from the computer-disk drive approach to a networked computer style, where applications and resources are available through the network in an invisible fashion. Jini also functions in an IP network and it is based on three parts, the client, a server and a lookup service. Jini is Java-based and thus requires a virtual machine to run, which also makes it an undesirable option for small low-power devices.

Bluetooth also contains a protocol for discovering devices and their services over the wireless link. However the range limitation of 10 metres (Bluetooth Class 1), the inability to remotely access another device, relatively high current consumption and the peer-to-peer-style architecture also makes Bluetooth a less desirable alternative for devices with limited resources. Bluetooth discovery can also be turned off from the client device, making it impossible for a server to locate it and discover its services.

Service Location Protocol (SLP) is a protocol developed for use in local area networks [Guttman99]. Each service broadcasts an URL for locating the service and a certain number of attributes that are related to the properties of the service. SLP is agent-based, consisting of Service Agents that advertise the URL and the attributes of their services, User Agents that perform search for services that are being requested and Directory Agents that perform cataloguing and caching tasks in the network. SLP is commonly used in printers and printing services, but a primary shortcoming of SLP is the lack of remote access of the service; it provides only location and contact information. The rest of the implementation is not specified and is left to the manufacturer.

FRODO [Sundramoorthy06] is a service discovery protocol developed at University of Twente in the Netherlands. Robustness and resource-awareness were key factors in its de-

velopment to make the protocol suitable for a home environment. FRODO includes three different classes for devices, categorised according to the estimated cost (and thus complexity and resources) of the device. The simplest ones, 3C (Cent) devices have restricted capabilities, e.g. sensors, 3D (Dollar) devices include more functionality and are able to use resources from other devices as well, e.g. temperature controllers. 300D (Dollar) devices are powerful and are able to maintain device and service registries. In reliability tests [Sundramoorthy06] FRODO has proven to be a tolerant protocol, comparing well with the previously mentioned standards.

The table below summarises properties of different service discovery protocols.

Table 7.1 Comparison between service discovery protocols [Sundramoorthy03].

Feature	UPnP	Jini	Bluetooth SDP	SLP	EPIS
Architecture	Peer-to-peer	Client-server Peer-to-peer	Peer-to-peer	Client-server Peer-to-peer	Client-server
Catalogue service	No	Lookup service	No	Directory agent	Directory agent
Leasing concept	Yes	Yes	No	Yes	Yes
Remote control	Yes	Yes	No	No	Yes
Scope of search	Device type Service type	Service type Service ID Attributes	Service type Attributes	Service type Attributes String	Service type Attributes Device ID
Robust	No	No	No	No	No
Resource awareness	No	No	No	No	Yes
Workload delegation	No	No	No	No	No

7.4 Early TUT Communication Protocols

Three generations of smart device communication protocols have been in use at TUT, each being improved on its predecessor. Protocols have been designed for fast parsing, light weight and simple implementation. Later, as requirements rose and complexity demanded more functions, protocols have also evolved together with the smart home system.

Primary requirements for these protocols have been the ability to receive and send commands consisting of a few bytes of data, send back an acknowledgement and contain a simple addressing feature.

7.4.1 Living Room Serial Protocol, “MOB-Bus”

The first communication protocol, used in the Living Room, was designed to be lightweight and it was targeted mainly at the infrared network, but it was also used in wired network nodes. The interface was a synchronous serial bus with separate clock and data lines. The maximum clock signal rate was 50 kHz. The data consisted of a header (“datapak”) byte followed by up to 15 data bytes. The header consisted of a fixed start field (4 bits) and a header, which contained the number of data bytes that followed. The following data byte would typically consist of a specific command to the recipient (e.g. measure temperature, adjust lights) and possibly other parameters (e.g. measure temperature in the kitchen, adjust living room lights). The network was of master/slave type, with the master device being responsible for creating the clock signal and initiating data transfer. After transferring 8 data bytes and one parity byte the slave device checks for possible parity errors. If none are found the next byte is transferred. In case the slave device wants to transfer data, it has to request this through the data bus.

The wired version had no addressing as it was considered a direct peer-to-peer connection, but the infrared network did use addressing. This was invisible to the devices themselves, however, with the infrared master and receiver managing this functionality.

The frame structure thus consisted of the following parts:

Header(0xA+4 bits),P + Data(8 bits),P + Data(8 bits),P + Data (8 bits),P + ...

“P” denotes a parity bit, which in this case was agreed to be even. The recipient of this data was required to respond within 1 ms by returning a special ‘”acknowledgement” - byte, 0x7E. This byte was also used to test the communication link and attached devices. In this case the master device sent 0x7E and the recipient replied by returning the same byte. Electrically data transfer looks like this:

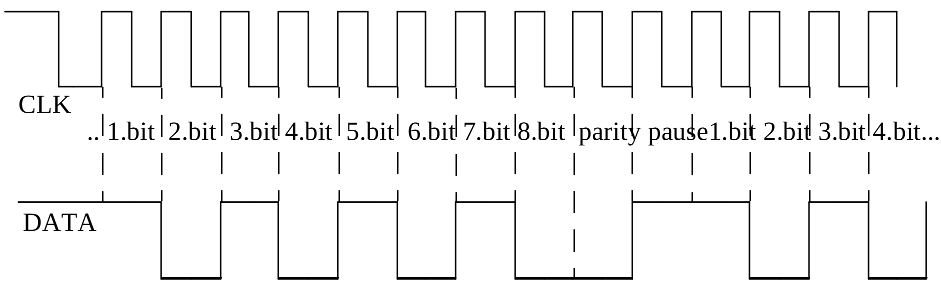

Figure 7.4 MOB-BUS communication.

From Fig. 7.4 top: CLK, bottom: DATA. In idle status both CLK and DATA are set to 1, data transfer is initiated from the master by pulling CLK low for 1 ms, after which the next clock cycle contains valid data. The slave can initiate data transfer by pulling DATA low and waiting for the master to react.

For example, for a temperature monitor the data sent for the ‘measure temperature’ - command (0x01) would have been:

0xA1,P + 0x01,P (fixed header 0A plus 1 data byte, followed by one command byte)

To which the recipient (temperature monitor) would initially reply with

0x7E,P (acknowledgement)

After this, the monitor would perform a temperature measurement, and send a reply back to the master. This reply would consist of a header, the measurement command, plus an additional data byte consisting of the actual measurement result:

0xA2,P + 0x01,P + 0xYY,P , where “YY” is the measurement result.

7.4.2 Smart Home Serial and UI Protocols

The Smart Home introduced more devices and new UIs, which partially meant that the old protocol and infrastructure were no longer able to cope with the increasing amount of functionality. A new serial protocol was written and partially tested in the Living Room, later to be followed by a separate protocol for UIs.

Smart Home Serial Protocol

The complexity and performance of the MOB-bus protocol became apparent as more devices were created. When it was decided to move away from the infrared links there was less need for the MOB protocol, and work started on a new version. As RS-232 interfaces were available in most microcontrollers and devices, it was a logical step to adopt this standard instead. The addition of addressing was important, as there could be numerous devices connected to a master using a serial hub or wireless link. The data structure (using “Datapak”) remained basically the same, consisting of three specific bytes (device address, header and a specific command). The header informs the receiving device how many bytes of data are to be expected in the data frame. After these three bytes it is also possible to send additional data and possible parameters (e.g. adjust lights in the living room) or data. The entire frame is composed of the following bytes:

[address][header][command][data, parameters etc..]

Every device connected to the serial hub (either by wire or through the RF network) has its own address, which translates into the physical port on the hub the device is plugged into. The communication speed is 19200 bps. For example, commanding the lights to be turned on in the living room would require the following command:

[0x01][0xA3] [0x01] [0x02] [0xFF]
[address][frame] [adjust lights] [living room] [maximum brightness]

Valid addresses for wired devices are 1 to 15 and 20 to 29 for wireless devices. Specifications also require devices to reply to a command within two seconds, otherwise the session will time out.

The new serial protocol performed more reliably than its synchronous predecessor, though there was still no collision detection or error correction in use. Collisions are theoretically possible even if all traffic is still being initiated from the network master. There is also a limit of how many bytes the serial hub can store in its memory, limiting the maximum number of bytes that can be transferred. The new serial protocol was used in the eHome and it is still in use in the Smart Home.

Smart Home UI Protocol

User interfaces in the Smart Home use a separate textual protocol, which allows UIs to create, modify and query a group of devices, send control messages and open/close connections. A new protocol was required, because the standard serial protocol was limited to a maximum of 15 data bytes, and its structure was also unsuitable for group messages and simultaneous transmission to multiple recipients. Smart Home UIs are connected to the server using TCP/IP socket connections, and whenever a change is detected the server broadcasts the new status to all connected UIs. A standard UI protocol message has the following structure:

[# length # version # command # IDGroup # ID # value #]

where "[" is a start character, "]" a stop character and "#" a delimiter character. The length field defines the total length of the message (maximum is 999), version indicates the UI version and command (e.g. adjust, create, delete, getvalue) denotes the desired action. IDgroup and ID number point to specific groups of devices or a single device, and the value field is an optional parameter. For example, adjusting a light in the living room (a dimmable light, ID number 2) to brightness value 50 would be done with the following command:

[#6#1#adjust#linear_lights#2#50#]

Once a command has been processed, an "adjusted"-message is sent back from the UI, which allows the server to update the state of the device and thus other UIs as well.

7.4.3 LIPS Service Discovery and Network Protocols

The LIPS project introduced new requirements for communications, and for this reason existing implementations were discarded and a new protocol designed. The ability to flexibly add devices, discover services and to implement better fault tolerance were primary design guidelines.

EPIS Service Discovery Protocol

EPIS, an Efficient Protocol for Intelligent Spaces, is a service discovery protocol designed for the LIPS-project. EPIS is a simple low-power protocol offering service discovery, data exchange and power saving schemes developed with low-power sensors and simple wireless networks in mind. EPIS uses a standard PC for running the main server software, keeping registry of known devices and continuously listening to the wireless network. Thus EPIS is also confined to a star topology, which on the one hand leaves all responsibility to the central node (and also a possible single point of failure) but on the other hand makes wireless nodes simpler as they only have to know the network address of the central node. Remote nodes are mote devices, as described in Chapter 6. Addressing is implemented using TinyOS 16-bit addresses, with 0xFFFF reserved for broadcast messages. Every wireless node has an individual network address that it responds to, and in addition to this address, one node can have one or several device addresses. This is required because a node, depending on the hardware configuration, can contain several sensors or connect to other external modules. With separate device and network addresses it is possible to access individual sensors or modules in the node. Each node also stores a set of coordinates (x,y,z) and a space variable (essentially an identifier for the room that the device is located in, e.g. bedroom, kitchen).

At certain intervals wireless nodes poll the network (listening for transmissions) in order to conserve battery power. Devices send out regular “heartbeats” that the server monitors. If a device fails to send a heartbeat for a certain amount of time, its address is released and the device is removed from the network. As the central node gets its electricity from the ac mains, it does not have to conserve power in the same way as remote nodes, and it is thus continuously listening to the network for any activity. This also allows it to respond to messages with minimal latencies. EPIS specifies three different power states for wireless devices. The “Active” state consumes the most power, but as heartbeat and polling intervals are kept short it also allows the device to react and send data as fast as possible. In the “Sleep” state these intervals are significantly lengthened and response times become much higher as a result. The device is still active, but computational power consumption is minimised. The “Standby” state maximises power savings; while maintaining the same timings as in sleep mode, all other functions are essentially shut down. The device is only responding to a wake-up message.

Device Registration Procedure

When a new device is introduced into the network it sends out a heartbeat message. When the server notices a message from an unregistered device, it initiates a login procedure by sending a registration request to the new node. The node responds with an acknowledgement and is given a new unique network address by the server. After this the device transmits an XML file containing the specifics, services and functions to the server. The coordinates and location of the device are also updated, either from the server to the device or vice versa.

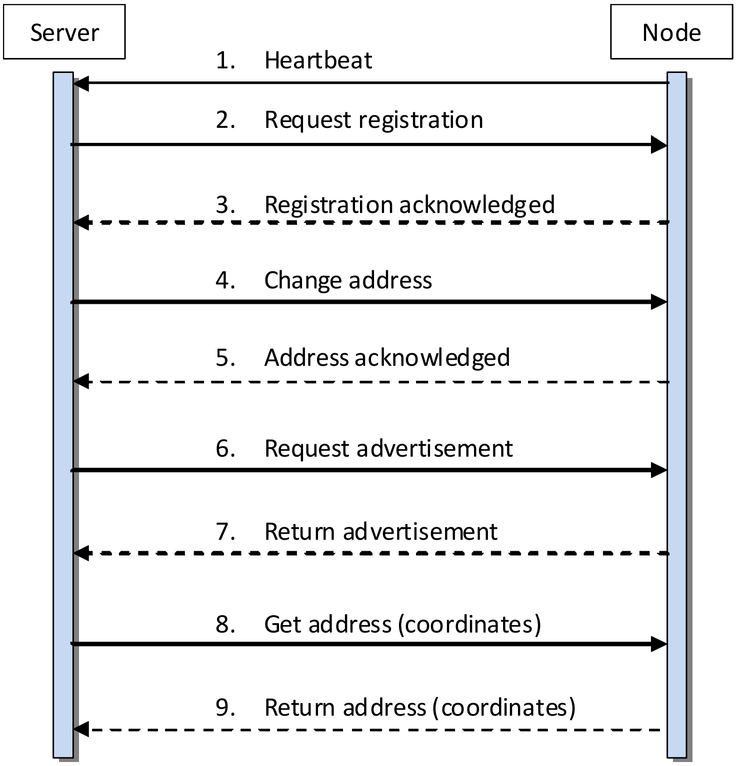

Figure 7.5 EPIS device registration procedure.

EPIS Network Protocol

EPIS network communication is encapsulated inside TinyOS headers. Thus the low-level communication is handled by the operating system using a header system similar to the protocols in the Smart Home. The message header consists of a message class and type (4 bits each), a 16-bit address (source or destination) and a 16-bit message ID. There are a total of five message classes: Heartbeat, Address, Attribute, Error and Service Discovery. Each class has a number of message types, for example, an address-class has message types for address changing, registration and acknowledgement.

[4 bit Message Class][4 bit Message Type][16 bit Address][16 bit Device ID]

EPIS message classes are:

- Heartbeat : Network control messages, device power state control
- Address : Login, messages addressing (change, release, request)
- Attribute : Read/Write device attributes
- Error : Reserved for error logging

- Service Discovery : Allows the server or device to perform service queries throughout the network, e.g. find all lights in the living room

Service Advertisement

Each device in the LIPS network contains an XML file that contains a description of its properties and services. The file contains device parameters that describe the physical device, its power saving features and service parameters that are related to what the device is able to perform. Device parameters include the following:

- **Device name** : A descriptive name of the device
- **Device type** : Type of the device, either a custom type or one out of the standardised device types (e.g. light or temperature sensor)
- **Poll period** : Time interval (in minutes) with which the device will re-announce its presence in the network.
- **Sleep poll period** : As above, but when device is in sleep mode
- **Listening period** : Describes how often the device listens to the network
- **Sleep listening period** : As above, but when in sleep mode
- **Connection** : Connection type, e.g. "mote" for devices that use a mote for connecting
- **Description** : Optional description of the device

Service parameters include the following:

- **Func** : Service function description in one word (e.g. lighting_level)
- **Value** : Initial default value
- **Valuetype** : Data type of the value (short, signed, unsigned, text etc.)
- **Rules** : Accessibility rules for values (read/write/both/none)
- **Minval** : Minimum legal value
- **Maxval** : Maximum legal value

Device Attributes

Each device can have up to 18 attributes, which can be stored into the memory on the device. The first two of these stored attributes are the x,y,z coordinates of the device and the space variable, both of which are assigned by the service discovery protocol. The remaining attributes can be freely assigned, and they can vary significantly between devices. For example, a light level sensor could store an exact floating point number indicating light levels in a certain space, or it could simply store a dark/light boolean value in its memory.

An attribute can either be a 32-bit value or an 8-bit ASCII string up to 96 characters in length. Different numerical formats (long, short, unsigned etc.) are accepted as well as boolean (true/false) values. Each attribute can be defined to have minimum and maximum values, current value, value type and privileges (write, read, write/read). An attribute can also be a free word description of its properties. Attributes for each device are described in the service advertisement message.

Below is a sample XML file, in this case it is for a sensor node containing temperature, humidity and light level sensors:

```
<?xml version="1.0" ?>
<!DOCTYPE device SYSTEM "properties.dtd">

<!-- Example definition file for a mote sensor device implementing -->
<!-- temperarure, humidity, photosynthetically active radiation and visible
-->
<!-- spectrum including infrared -->

<!-- Heartbeat interval is 30 minutes in active state and 60 minutes -->
<!-- in sleep state. -->
<!-- This application doesn't require short sleep intervals (preamble), -->
<!-- 500 ms in normal state and 10000 ms in sleep state. -->
<device name="MoteDevice" type="mote"
         poll_period="30" sleep_poll_period="60"
         preamble="30000" sleep_preamble="30000"
         conn="Tiny" set="ON">

<!-- DEVICE ATTRIBUTES -->

<!-- Attribute: Temperature (INDEX 2)-->
<!-- 16-bit unsigned integer, fixed point 6b + 8b -->
<!-- Read-only attribute -->
<opt func="temperature" value="0x0" valuetype="uint" minval="0"
maxval="0x3FFF" rules="read">
<descr>Temperature</descr>
</opt>

<!-- Attribute: Relative humidity (INDEX 3)-->
<!-- 16-bit unsigned integer, used 12b -->
<!-- Read-only attribute -->
<opt func="temperature" value="0x0" valuetype="uint" rules="read">
<descr>Relative humidity</descr>
</opt>

<!-- Attribute: Visible light (INDEX 4) -->
         <!-- (photosynthetically active range, 300-700 nm) -->
<!-- 16-bit unsigned integer, used 12b -->
<!-- Read-only attribute -->
<opt     func="visible_light_level"     value="0x0000"     valuetype="uint"
rules="read">
<descr>Visible  light  level  (photosynthesis  active  range)(1&lt;=dark,
150~bright office light, 1350&gt;=bright sunset</descr>
</opt>

<!-- Attribute: Solar light (INDEX 5)-->
         <!-- (Full visible spectrum + ir-radioation, 300-1100 nm) -->
<!-- 16-bit unsigned integer, used 12b -->
<!-- Read-only attribute -->
<opt func="solar_light_level" value="0x0000" valuetype="uint" rules="read">
<descr>Solar  light  level  (Visible  light  spectrum  +  ir-radiation)(0=dark,
210~bright office light, 1500&gt;=bright sunset</descr>
</opt>
```

```
<!-- Attribute: Sensor report interval (INDEX 6)-->
<!-- 16-bit unsigned integer -->
<!-- Read-only attribute -->
<opt   func="sensor_report_interval"   value="0x0001"   valuetype="uint"
rules="both">
<descr>Sensor report interval in minutes, 0 disables reporting</descr>
</opt>

</device>
```

7.5 Embedded Software

As processors, microcontrollers and different kinds of programmable chips have become cheaper and more powerful during the years, they have found their way into ordinary devices that are used in daily life. As a consequence these devices also contain fairly complex software that has been written for a specific application. White goods, such as washing machines, microwave ovens, etc. have their own rather straightforward tasks and programs while higher-end DVD players, TVs and stereo sets are able to connect to home networks, read USB memory keys and display pictures from digital cameras. Even tiny temperature sensors, fingerprint readers and light switches can contain embedded software. Since the applications and requirements vary significantly, it is clear that the embedded software in all these devices can also vary considerably from device to device. In theory, it matters little what programming language has been used for writing the software, what kind of CPU it runs on or how the device interfaces with the rest of the world, provided it conforms to certain standards and protocols. This is also a reason that systems designed at TUT use text-based messages for communicating with each other (e.g. the Smart Home UI protocol); they are easy to parse even in microcontrollers, they are easy for developers to debug and they are platform-independent.

For more demanding applications there are many options available. Certain real-time operating systems (RTOS), such as uC/OS-II [UCOS], allow software to be written to run in “almost real time” (e.g. meaning that it is possible to create tasks that complete within a specific time frame) creation of multiple tasks and implementing task scheduling. Such operating systems naturally consume more resources than a customised software written for a specific purpose. However, when more tasks are added and if multiple similar applications are implemented, it makes sense to move to a common expandable platform upon which new components can easily be implemented. The alternatives are other (non-real-time) operating systems, such as the TinyOS mentioned earlier.

Fig. 7.6 shows the flow of a typical Smart Home device software. After initialisation the software loops and waits for data to be received. After reception the software checks the received data, performs a measurement or adjustment and sends a status report and acknowledgement to the server.

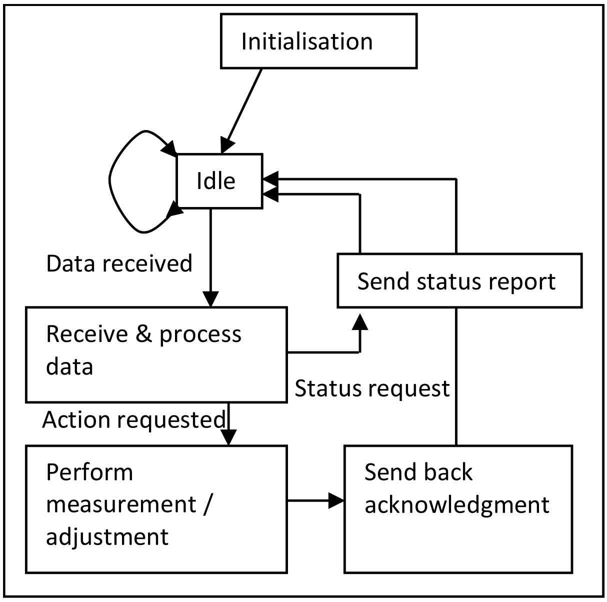

Figure 7.6 Functionality of the software of a simple smart home device.

7.6 Discussion

Requirements for proper smart home software seem immense; it has to be adaptive, modular, stable and intelligent. Thus a great deal of care has to be taken in the design and testing process in order to ensure a reliable and usable home control platform. Standardised middleware platforms, such as OSGi, make the design process easier by providing contributors the required building blocks. Universal Plug and Play and similar protocols on the other hand can assist in inter-device connectivity. In the case of a single server running middleware software functionality is centralised, making it easier to debug but also makes the system vulnerable to errors and failures. Distributed middleware components increase fault tolerance but it also makes it more difficult to locate errors and faults as there might not be any clear indication of where the fault has occurred.

Challenges with smart home software are clearly related to artificial intelligence and adaptivity, as these are the most complex parts of the system. Creating a set of rules and behavioural patterns, constantly monitoring actions in the environment and correctly anticipating future actions are complicated tasks for any piece of software.

Perhaps equally important are service discovery protocols, which can significantly ease the intialisation and set up -process, as a lot of steps that previously have involved user action can now be performed by the system. Furthermore, it will bring additional benefits in the long run as the system is being modified and updated and as mobile devices join and leave the home network. The first communication protocols designed at TUT have been

extremely simple and lightweight, but with the introduction of the EPIS protocol a big step towards dynamic networks has been made.

IST requirements for AmI technologies [ISTAG03] also concern software, for example regarding self-configuration and on-the-fly programming. The former is important for adaptive environments and is essentially service discovery on a larger scale, enabing devices to adapt themselves to the environment. For example, sensors can change parameters according to how quickly they have to react and a motorised door would keep the door open a longer time if the home is occupied by elderly people. On-the-fly programming is a way of configuring devices without requiring them to be removed from their operating environment. This method is, however, a larger task than simple reconfiguration, as it practically reprograms the entire device, allowing it to be modified to conform to a new communication protocol, for example.

7.7 Summary

A crucial part of the smart home infrastructure is the middleware, which is responsible for connections, translations and user interfaces. Properly designed, modular middleware architecture allows the environment to be modified at any time, accepts the addition or removal of devices and is adequately fault tolerant. A suitable middleware reduces the need for compatible protocols, but does not render the system completely independent of communication protocols as these still lay the grounds for all communication in the smart home. Together with artificial intelligence and adaptive control software it can make the smart home a pleasant, functional environment for the users.

8. User Interfaces

In an ideal case a smart home would not require any special interactions or UIs, as the home would learn to anticipate what users want to do and react to changes and situations by constantly monitoring the users' actions [Mozer99]. In practice, however, some kinds of UIs are required for making more complex adjustments or remote control. UIs are, after all, the primary means of communication and interaction between users and the home control system. These also present the most challenging design problems, as there are different requirements for different users and devices. Smart homes present endless new possibilities as far as UIs are concerned [Dey01_2], and in order to maintain usability and practicality, great care has to be taken when choosing and designing these UIs. Generally speaking user interfaces should have the following properties:

- Intuitive (logical and easy to understand)
- Consistent (they work as expected, every time)
- Configurable (users can, if they want to, change the way the UI works)
- Adaptive (UI changes according to the context or user)
- Simple (not too complicated, easy to use)

These quite similar to general requirements described in Sections 3.2.1 and 3.2.2, which underlines once again the importance of well-designed UIs. Smart home UIs can be divided into three main categories: natural UIs, computerised UIs and mobile UIs, although the distinction is not always clear and sometimes an UI can belong to several categories [VTT03].

Natural UIs (i.e. traditional ways of using devices and equipment such as buttons, levers, handles, etc.) offer users a tangible UI and a physical way of interacting with equipment [VTT03]. The name derives partly from the way that equipment has been used for generations. For example a hammer, a door handle and a vacuum cleaner have remained relatively unchanged through the years, and their use is generally well-known. Their UIs have evolved to a point where the most logical and suitable designs have become de-facto standards. Light switches and home appliance controls have also remained mostly unchanged, but there are also instances where these have been radically changed to offer new ways of control. Completely changing the way of controlling everyday items might lead to confusion and frustration among users, at least until users are more familiar with the technology. On the other hand changes are required if progress is to be made.

Computerised UIs, such as graphical UIs and touch screens depend on some form of infrastructure such as displays, buttons or computers. If designed properly, these are easy for people to use without recourse to user manuals, but less visual UIs (buttons, panels, etc.) can be less intuitive.

Mobile UIs are usually located in personal portable devices, and they can thus reside in any location. Because of this, mobile UIs can be used in many different environments to control various items. For example, in a sports stadium users can access information on the

game, players or statistics and in a shop they can access prices, shopping lists and so on. When an occupant returns home, mobile devices can synchronise data that they have collected during the day and access updated information from the home server. In the past, resources of mobile devices have been rather limited, but with advances in battery and electronics technology this problem is rapidly diminishing.

In general, the interaction between computers and users in smart homes requires new kinds of user interfaces, as the activities are typically non-computational. Interfaces for offices, computer environments and information processing etc. are generally unsuitable as they are designed for another purpose [Coen98]. Thus the human-computer interaction should become less explicit and more closely connected to the environment and situation in which it is being performed. The ultimate goal would be to have UIs disappear into the background, becoming visible only as needed [Dey01_2]. According to the authors there are different levels of "invisibility": Truly invisible (UI is completely unnoticeable to the user and integrated into the environment, interaction with the user is implicit), transparent (UI is not physically invisible but users are not explicitly aware that they are using them) and subordinated (the functional side of the UI is subordinated to another aspect, for example, aesthetic or personal).

Nonetheless, it is beneficial [Green04, Koskela04_1] to maintain traditional manual controls for equipment and instead offer other, new ways of controlling them all. Practical studies have shown [Randall03, Koskela03] that centralising all smart home UIs into a single master UI (for example, a touch panel on the wall or a web-based UI) is not beneficial, as there are already multiple different scenarios in everyday family routines. A centralised control panel, for example, might be useful when people are nearby, but there will be cases where the UI is out of reach of the user and which might prompt the user into using manual controls or doing nothing at all.

Physical, graphical and auditory user interfaces can all be utilised, each having its own purposes and advantages. In the ubiquitous computing scenario, UIs can be detached from their respective devices and placed anywhere. This makes it possible to group UIs and use any device from any UI. However, this feature also requires more complexity from the UIs, since it is now possible for several people to control a device at the same time. Multi-user issues can be accommodated either by assigning priorities to users (users with higher priority overrule others) or by simply offering first come-first serve -type functionality.

One important UI-related issue is latency; if it takes a noticeable time for the issued command to be executed, it is easily perceived as annoying or even as a malfunction. A latency of a few hundred milliseconds is already discernable [Koskela03], whilst a second or more already makes the user question if the command has been received at all. This can lead to people issuing a repeat command, which eventually leads to multiple commands being executed, possibly cancelling each other out. In smart home scenarios this is evident in the case of lighting control, for example, because the results are immediately visible.

Smart home UIs can also be adaptive, i.e. they can display information and controls that are relevant to the user at a particular moment [Tiresias08]. For example, during daytime

a control panel might display controls for adjusting blinds or opening windows, whereas in the night it would instead display controls for adjusting lights.

This chapter discusses important elements of smart home user interfaces, various implementations and other ways of interacting with the environment. The approach taken is mainly technical, since usability and related issues lie outside the scope of this thesis.

8.1 Feedback

User interfaces also need to provide suitable feedback so that for users will know if an action has been successful or not. It can be rather confusing for the user if nothing happens when an action is issued. A well-designed UI will clearly indicate that an action has been taken; a button can give a satisfying “click” or a software beep when it is pressed, a graphical UI might change the colour of a button icon when it has been pressed or a light is turned on as a result. Studies have shown that it is effective to combine different kinds of feedback to improve functionality and usability [Emery03]. People with special needs, such as the elderly, blind or deaf could also greatly benefit from different kinds of feedback, enabling them to use computers and home equipment with greater ease.

Main categories of UI-related feedback are visual, auditory and haptic feedback. Visual feedback comprises different kinds of lights and indicators that catch the user’s attention by turning on or blinking, for example. Tangible mechanical UIs, like switches, buttons and levers also indicate their state to users by visual means: light switches remain in the position that they were set to, a software button shows whether it is on or off with a label, etc. Physical elements also offer direct confirmation that an action has been taken (i.e. lights turn on, door opens), but this is not always evident to users, depending on ambient noise, light and similar conditions. In graphical UIs similar approaches can be taken, with on-screen buttons changing colour or shape when activated, with icons indicating status or simply with a text string.

Auditory feedback ranges from the buzzing sounds of equipment operating to beeps, indicator sounds and related status sounds. More sophisticated audio feedback uses spoken or synthesised vocal messages to read messages aloud. Auditory feedback is often used as a supplementary method combined with haptic or visual feedback [Emery03].

Haptic feedback utilises physical means of communication. Switches and other physical UIs usually have tactile properties, and when used they clearly “click” or physically communicate action in an obvious way. Haptic feedback is also achieved by vibration, as is the case with mobile phones and computer games (force feedback).

8.2 Context Aware UIs

Context awareness can be a valuable asset in smart home UIs. If an UI knows who is using it, where and under what kinds of circumstances, there are numerous advantages that such information can provide. Things that a context aware UI can enable include changing the functions available and presenting functions that are predicted to be useful to the user. Fur-

thermore, the UI layout can be customised for each user and appropriate feedback can be directed at the user depending on the location and situation.

For example, the speech recognition UI in the Smart Home described in Chapter 5 locates the user and is able to direct audio feedback and use commands related to the room the user is in. Another experimental UI [Ritala03_2] was designed to replace standard infrared remote controls and light switches, becoming a portable universal UI for the home. The remote control has only a four-way rocker switch and a small display, and the functions available on the screen change according to the device or function that is being controlled. In order to detect which device is being controlled, the remote has an infrared receiver. Small infrared tags are placed near controllable devices and various other locations in the home (the remote is able to use SCARS infrared positioning), and when the remote control is pointed at such a tag, it recognises the device and displays the appropriate information to the user. Commands are transmitted from the remote to the home server over an RF link. With the ability to sense which device the user wishes to control, it is possible to present only the relevant controls. This makes it easier for the user to select appropriate actions instead of having to use separate remote controls for each device or browse through a complex menu structure on a graphical UI.

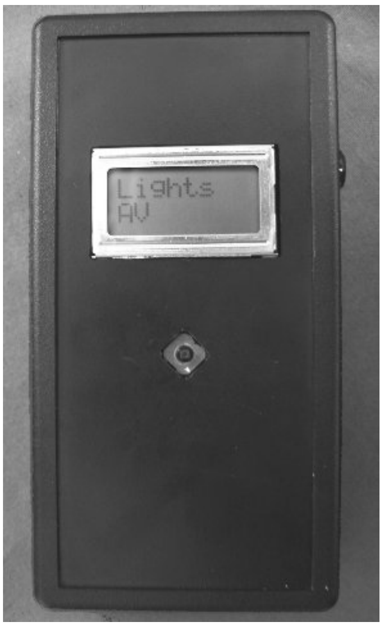

Figure 8.1 Context-aware remote controller prototype [Ritala03_2].

ContextPhone [Raento05] is an application for mobile phones using the popular Series 60 [S60] platform. ContextPhone attempts to discover the context of the user by using information that it can gather using sensors in the phone, cellular network, notes in the calendar etc. This information is also shared with other people and passed onto other applications running in the phone. Sensors used by the software include microphone and camera (for

context sharing), Bluetooth (used for detecting other nearby phones) and network cell information (for obtaining a rough location estimate). Further information is received from applications and settings from the phone itself (active profiles, open applications, recent activities etc.) In a context-aware contact list in ContextPhone users can see the context of their contact and decide whether or not the contact can be reached. For example, a person in a meeting would have a silent profile activated, be surrounded by other people and be near a meeting room WLAN hotspot. ContextPhone also allows users to exchange presence information using text and multimedia messages or through short-range wireless communication. ContextPhone software is available from the author's website.

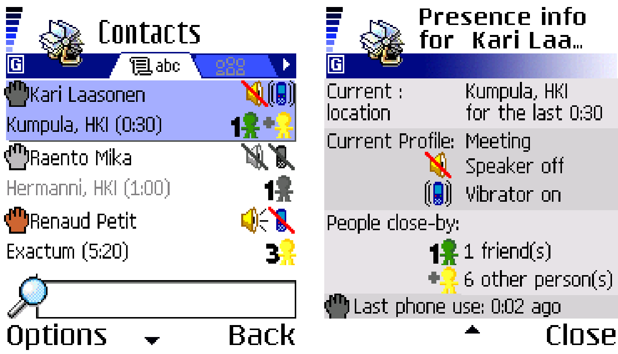

Figure 8.2 Screenshots of Context Phone. Photo: Mika Raento

8.3 Physical UIs

Physical interfaces, such as buttons, levers and other natural user interfaces are the most intuitive types of UIs for people to use, and are as such the most popular controls for mechanical equipment. Buttons, switches and levers are familiar to users and they provide a physical and recognisable action when they are used. However, even traditional physical UIs can be enhanced by other means. For example, new kinds of functions can be added to traditional UIs like switches and pushbuttons; in smart homes wall switches can be programmed to control a specific light source or groups of lights. One switch, for example, can turn off all lights in the home, making it less likely the user will leave a light on after leaving the house. In addition to controlling lights, the buttons can be configured for numerous other tasks or almost any function in the home. Thus we still maintain the traditional physical UIs while we are able to change their functions to something that would have been very costly or difficult to implement without smart home hardware.

The major advantage of physical UIs is that their shapes can already indicate the kinds of actions they can perform, and their physical existence means that, unlike graphical or other virtual representations, they cannot accidentally "disappear" or be closed [Mäyrä05]. To some degree, a physical device can represent a virtual counterpart (for example, a digital photo frame) but in some cases physical size can become a limiting factor, making interaction too cumbersome or impractical.

8.4 Graphical UIs

Graphical interfaces have become commonplace since the 1990s with the emergence of graphical windowing operating systems and applications. Graphical UIs are easily readable and can display a great deal of information that other kinds of UIs cannot easily present. Another advantage is that the UI can be easily reconfigured to represent any information in any form, making it possible to personalise UIs for different users or user groups. For example, a wall-mounted graphical home control panel could restrict access to certain features for children, and for the elderly it could display larger buttons and text with bigger fonts. Naturally, a graphical UI is only good if it is well-designed; poor usability and readability can make it even harder to use than more traditional UIs. Graphical UIs can nowadays be implemented in a wide variety of devices. PCs, internet tablets, PDAs, wall panels, mobile phones and even home appliances are just some examples, and the list of devices continues to grow. The physical size of the screens can be an obvious practical limitation to their implementation, with smaller screens needing back up from larger ones to display complex data or enhanced visualisations.

8.5 Auditory UIs

Another natural way for humans to interact is by speaking, and auditory UIs are an interesting way of interfacing with the smart home system. Speech recognition software has made great progress and, even though still not perfect, there are programmes that can already process and recognise a a variety of commands efficiently. Using speech as a form of interaction allows users to focus their attention elsewhere since there is no need to concentrate on reading text on a screen, pressing buttons etc. [Coen98]. Moreover, the increasing complexity of graphical user interfaces and the number of available functions in a smart environment call for more intuitive ways of interfacing with the home system. This is especially important when considering mobile devices and other applications where UIs are usually restricted in size; small screens and tiny buttons can reduce usability drastically. A speech control interface would usefully allow hands-free operation in numerous common everyday situations such as when coming home from the grocery store carrying large shopping bags or when the physical controls are out of reach.

Text-to-speech synthesizers can create audio feedback and read aloud e-mails, news items and other important notifications. Audio feedback can be directed to the room where the user is present, and the system can be made to read any text string that the server produces. This way it is possible to construct a system that would listen to commands from users, process them and provide audio feedback back to users. The practical implementation would be more difficult because microphones must be used, either requiring users to carry them around or to integrate them into another device, furniture or even structures in the building itself. Background noise is also a problem, causing problems for speech recognition software. The process of separating commands from other sounds is another major challenge. Nevertheless, a speech control UI integrated into a mobile phone, for example, would give users another way of interacting with their home electronics.

8.6 UIs in Other Smart Home Projects

8.6.1 InfoCube

The InfoCube (developed as a joint project between TUT and the University of Lapland) is a cubic, wireless device that can be used as a 3D controller for a 3D user interface [Kaila05_4]. The goal of the InfoCube project was to create a natural way of interfacing with a 3D user interface. It would be suitable for usage in a smart environment or in virtual environments. The 15 x 15 x 15 cm wooden cube is aware of its angular movement and velocity, which are measured to control a visual 3D-user interface depicting a virtual cube on the screen. The model is used to create visual and haptic feedback to the user, by means of which decisions can be make from visual information and the position of the cube. Rotating the actual cube will also cause an identical movement of the virtual cube on the screen, resulting in a very intuitive, interactive interface. A sample application consisted of an image projected on a wall screen showing a rotating cube with pictures of different television channels on each side, and can be seen in Figure 9.1. When users want to change the television channel, they simply pick up the cube and rotate it in their hands. The cube on the screen will rotate accordingly, and users can see the contents of the different television channels. When they find the channel that they want to watch, they simply squeeze the cube on the appropriate side and the selected channel will pop up and become fully visible.

Other applications for the cube include controlling similar 3D-user interfaces and navigating through menus. The cube could also be used in computer games, and since it is wireless and battery powered, there are no cables to restrict its range and movement.

Figure 8.3 InfoCube prototype.

8.6.2 Microsoft Surface

Microsoft [Bathiche07] has been developing a large tabletop surface, which acts both as a display and an interactive touch-sensitive surface. The tabletop screen allows multiple users to view graphical elements and interact with them by touching the table surface. This technology would fit well into smart homes, as the entire family could browse the home functions and make necessary adjustments together. The Surface table is still being developed, but similar technology is already available, albeit in smaller sizes; touch screens and LCD monitors, tablet computers and computer vision applications.

Figure 8.4 Microsoft Surface. Photo courtesy of Microsoft Corporation.

8.6.3 Speech control

Speech is a natural form of interaction for people, and speech recognition has been used in many related applications (offices, computer control for blind people, alternative input method for PCs etc.) for a number of years. Spoken commands make it possible to interact more naturally with home equipment, for example, by asking for instructions or by issuing specific commands relevant to the user's context. However, smart home applications still suffer from significant challenges in the form of ambient noise, music, unwanted speakers, differences in voices between different users and the vast amount of possible voice commands. The noise is similar to the sounds that the speech control system actually wants to listen to, making it even harder to eliminate. However, using technology similar to that

used in mobile phone hands-free sets it is possible to filter out unwanted sounds and process the voice that gives the commands [Potamitis03].

8.6.4 Gesture Control

The human body can be used for making gestures that can be recognised with computer vision using cameras and video processing tools. Gestures include pointing [Jojic00], forms of sign language or facial expressions. For example, waving a hand could initiate a sequence to turn on the television, lifting both hands in the air could mean that the user wants to load an exercise program, etc. Gesture control typically relies on either body-mounted sensors or computer vision for recognising different gestures. With wearable sensors, such as the gesture pendant [Gandy00], recognition can be achieved anywhere, but at the cost of the discomfort of wearing sensor bands and battery packs. Computer vision can be used only in front of cameras, and is largely dependent on lighting, position of the user and other visual conditions. Gesture controls could also be implemented using other kinds of sensors, such as capacitive floor sensor arrays. If the sensor array is accurate enough, users could double-tap or make a foot movement in front of the door to open it.

8.6.5 Augmented Reality

Augmented Reality (AR) is a technology that combines what we can perceive from the environment around us using vision, touch and hearing with artificial, usually computer-generated information. Experiments with AR - enhanced smart spaces have been made at Columbia University and Xerox Laboratories [MacIntyre98] using both auditory and visual augmentations. According to the authors, humans should interact with smart spaces using means that are already natural for us, such as speech, context, affect. In other words, humans should forget that they are interacting with a computer when they interact with a smart space. With visual AR the user has a head-mounted display to see both the surrounding environment and the overlaid computer-generated information at the same time. This enables the smart space to present contextual information on a specific user, and this information can be seen only by the individual in question. Worn information displays can further be augmented by wall-mounted and other displays in the space, allowing information to be split into private and public sections.

Auditory augmentation is achieved by using a set of speakers, microphones and worn infrared badges. People can listen to audio messages or they can record auditory footprints for others to hear. Audio messages can be tied to the physical location of the user, the user's context or other relevant information. There are problems, however with such a setup since information presented from speakers is not private, and it is also impossible to direct information to a single user without using precise locationing and user recognition systems (or headphones).

The Digital Desk [Wellner93] is a physical desktop environment with a pair of projectors that are used for projecting images onto the desktop or onto documents placed on top of the desk. Cameras detect the motion and track the actions of the user (either fingertip or

pen) and also read paper documents that are placed on the desk. With the Digital Desk users are able to “drag and drop” images or paper documents by moving them digitally to other areas on the desk. These will then be combined digitally to form a new document. Other applications include a drawing program, calculator and remote interaction with another user also using a Digital Desk.

Another example of an augmented UI is using standard camera phones as computer augmented user interfaces [Rohs05]. The display of the phone, when set to function as the camera viewfinder, normally displays the image obtained directly from the camera. In addition, the software running in the phone is able to detect when the camera is pointed at a smart object or a controllable device. Identification is achieved by machine readable tags that the software detects from the image information. When the object is centred on the screen, a user interface for the particular device would appear on the screen for the user to use. Thus, by turning on the camera and by moving the phone around in the smart space, users would be able to find and activate controllable devices easily.

8.6.6 Calm Technology

The term Calm Technology was coined by Mark Weiser [Weiser96] to describe the process of designing the kind of technology that does not overwhelm the user with a surfeit of information or command attention in annoying ways. Calm Technology attempts to provide information on a human scale and also remain unobtrusive. Calm Technology moves between the centre and periphery of the user's attention depending on the nature and urgency of the information. Humans are able to follow several events simultaneously, but there are limits to the number than can demand our full attention. By moving events to the periphery of our attention we are still able to follow them without too much loss of detail or being overburdened by a plethora of data. This enables our attention to focus on more crucial issues when needed.

Not all technology can or should be calm, but for many everyday applications in the near future Calm Technology may enrich and enhance human-computer interaction.

8.7 Control UI vs. Centralised UI

A control UI is designed to control functions and the state of a device. Typically it is located on the device itself, for example, buttons, dials and displays on the front panel of a washing machine or a menu structure in a mobile phone. In a ubiquitous computing scenario, control interfaces can be physically separated from devices and brought together to another place to form a versatile, universal UI. This would allow almost any device to be controlled from any UI (allowing for certain UI restrictions). For example, a washing machine could be controlled from a mobile phone, but the phone could not necessarily be controllable from the washing machine due to the limitations of its UI. Both could, however be controlled from a graphical UI on a PC.

A centralised UI would be a location from where all devices and appliances could be controlled remotely. Examples of such UIs are the tablet UI in the Smart Home and the WWW UI in the eHome. There are cases where removing the control UI or replicating it on a central UI is not necessary or useful, for example in the case of the washing machine. Perhaps it would be useful to monitor the machine or select a washing programme from the remote UI, but the laundry still has to be manually loaded into the machine, making a remote controlling facility seem unnecessary.

Ideally, as every appliance and device in a smart environment is able to share its functionality to other devices, a question about where the UI tasks should be handled arises [Ritala05]. The first option is to mange all processing in the device itself, i.e. UI menus and task descriptions are transferred to the remote device (essentially a dumb terminal that knows nothing about the device that is being controlled). The second option is to have some processing and handling done in the UI device, leaving only commands to be sent to the target device. Intermediate solutions can also be made, depending on the processing power of the target and UI devices. If processing is allocated to the UI device this conserves resources expended on other devices since these no longer require as much processing power. Maintenance also becomes simpler because future updates are required only for the software in the UI device. It is not always clear, however, in which way functionality should be shared, and therefore it must be considered in terms of each individual case and scenario.

8.8 Natural UIs

Natural UIs are essentially specialised control UIs that have long-established roles for each device. The concept of natural user interfaces involves items that are designed to fit a purpose, as described earlier in the beginning of this chapter. For example, door handles can have different forms and shapes but in general people are aware of how they are used no matter where in the world they travel. In addition to the physical aspect, natural UIs also include forms of interaction that are natural to people, such as gestures, speech and touch [VTT03].

Whatever the case, there is no need to change the natural way in which we use certain devices, if we add electronics and connectivity to a certain device it merely adds to the functionality without altering the traditional way of using it [Vanhala02]. For example, a smart flowerpot capable of measuring water level, humidity and the temperature of the flower can alert the user if the plant needs attention. But the pot will not water the flower automatically; this must be done in the conventional way with the aid of a watering can. Motorised window blinds can be controlled through a graphical UI by using sliders and position controls, but it is still also possible to adjust them by hand by turning a knob.

Thus, preserving natural UIs is recommended wherever possible, as it allows people to use the device in a familiar manner. Enabling manual physical control for all devices is also essential to ensure that there is always a way to control devices, even if the central computer or network is inoperable or if direct manual control is desired for some reason. Even if the device is controlled from a graphical UI it is often possible to recreate the natural

way of controlling it on the screen, for example by using a virtual representation of the controllable device.

8.9 Different Types of Smart Home UIs

The types of UIs that smart homes can contain are almost limitless, but some of the most popular can be categorised as follows:

- Various types of graphical UIs (GUIs), using different kinds of displays and monitors. Graphical UIs can present a lot of information at the same time, they are easily reconfigurable and they can be tailored to suit a specific application or user group.

- Touch screens, mounted on the wall (wall panels,), tablet PCs and mobile phones. These are essentially a subgroup of GUIs, but they introduce a more physical element into control by offering physical-like controls and interaction. For example, a light dimmer control, such as a graphical model of a dial on a traditional mouse-operated GUI requires precise mouse movement whereas on a touch screen, could be in the form of a slider that users can simply drag into a desired position.

- Mechanical switches, buttons, levers, etc. These can be fixed (wall-mounted, for example) or mobile (wireless, portable or attached to another mobile device). Switches that are computer-readable can be programmed to perform almost any function in the home. A portable, wireless switch could be helpful for wheelchair users, for example, being much easier to use than reaching for wall-mounted switches. When location awareness is added, a context-aware light control could be implemented.

- Touch-sensitive areas, using various types of technology for sensing touch, weight or pressure (floor sensors, capacitive film, pressure-sensitive switches, strain gauges). An array of floor sensors could also function as UIs, for example, double-tapping with the foot in front of the door could indicate a desire to communicate to the home software that the door should be opened. These UIs might be completely hidden inside the home structures or furniture, which might make them impossible for guests to detect and use, but they would also be unobtrusive for people who know where they are and how they operate.

- Auditory UIs that recognise sounds, for example, the classical light switch that recognises the sound of hand clapping. More advanced features are available through speech recognition using microphones and recognition software, but problems arise when ambient sound levels rise, making it difficult to filter out spoken words from background noise.

- Optical sensors that detect changes in light level (light level sensor), recognise shapes (low-resolution IR or video camera) or motion (passive IR) are on the borderline between sensors and UIs. These sensors provide adequate information for detecting whether a person is present, mobile or if the surroundings have changes. This infor-

mation could be used as an input method, thus communicating a request for a certain action. Computer vision is the most advanced alternative. Using one or more video cameras and video processing software or hardware, it can be used for recognising patterns, individuals or motion.

- Mobile UIs that include mobile phones, remote controls etc. These include numerous everyday items like garage door openers, infrared remote controls, touch screen tablets and other kinds of portable hardware.

- Wearable computing can also introduce new UIs for smart homes, using UI functionality on the garments themselves. For example, a jacket with integrated textile buttons can turn into a home remote control when the user enters the building. Furthermore, possible UI elements on the wearable item, such as wristbands, watches and bracelets, can be integrated in the home control system.

- Tangible UIs are objects that can be manipulated in a physical way to perform tasks. They can represent a real physical object (e.g. a remote control or a ball) or be completely different from the object they are control. Tangible UIs can provide users with multiple ways of controlling equipment, for example, through touch, movement or visual means.

- Augmented UIs, as previously described, combine what we can perceive in the real world with artificially-generated information. This augmented information can be visual, auditory or haptic in nature, and using various user interfaces it is possible to overlay this information with information that we gather using our senses. The problems with augmented UIs are that they usually require users to wear certain equipment, such as head-mounted displays or haptic force feedback devices.

- Affective Computing [Lisetti98] is computing that relates to human emotions, using sensors to detect and analyse facial expressions, speech and gestures. While the computer can be made to read certain human emotions, the reverse process poses much greater challenges.

8.10 Summary

User interfaces are ideally the only parts of the smart home visible to the users, and thus their importance is crucial. Fortunately there are many choices and ways UIs can be implemented, making it possible to choose the UI best suited for a particular lifestyle and situation. Furthermore, it would seem that users will benefit from having several UIs to choose from, making it possible for users to pick the UI that best suits the situation. In cases where computerised UIs are unavailable, or if users merely do not want to use them, manual controls have to be enabled. With properly designed UIs it will be easier to control various appliances in the home, add new ones and manage difficult situations. For users this will instil a sense of security and comfort while also lowering the threshold for human-computer interaction. As sensor technology and artificial intelligence progresses new ways of multimodal interaction with the home environment will also emerge, paving the way for

even more natural user interfaces. Capturing and understanding context is another challenge that requires effort from both software engineering and sensor technology, and when fully realised it will further enhance the smart home user experience.

UIs used in TUT smart home projects include graphical, physical, auditory and mobile, whereas more complex UIs, and those that would require heavy data processing, have not been implemented. As the amount of sensors and devices in the home increases it also creates new possibilities for creating exciting UIs that can give users new ways of interacting with the smart home system.

9. Findings

This chapter presents findings and observations on the smart home projects at TUT. These are based on several years of practical experience working with the projects as well as continuous evaluation of their development. Findings on three smart home projects are presented.

9.1 Findings From the Living Room

One key design goal of the Living Room was to create a relaxing, comfortable living space and, based on the opinions of those who used the space, this design goal was achieved. Soft ambient lighting, comfortable furniture and no visible electronics or devices made the Living Room an ideal testing space, which is still deeply missed among researchers. A large projection screen and good home theatre equipment also made the living room area a cosy place to watch movies. User activation was encouraged by means of versatile monitoring and controlling facilities through the touch screen UI. The UI seemed to be well designed as it was easy to use without any greater learning effort. However, there remained one large UI-related problem: the tabletop PC was still a rather fixed fitting and because it was the only UI in the Living Room, it was sometimes in the wrong place (or turned off) when users wanted to make adjustments or check settings. A more distributed and mobile way of controlling the home would have been more useful. During the Living Room project resources were devoted primarily to creating new hardware, developing different communications networks and building applications for the testing space. Thus additional user interfaces and artificial intelligence were regarded as secondary considerations at the time. As many things were new to the newly-formed research team, many valuable lessons were learned during design of networks, protocols and devices. The project members gained valuable learning experience through activities such as programming microcontrollers, making robust electronics design and complying with common standards.

In 2001 the research team participated in the Futuuri- exhibition which was held in conjunction with the MindTrek 2001 conference in Tampere, Finland. Most hardware and furniture from the Living Room was transported to the exhibition area and a new living space was constructed. The theme of the exhibition was future technologies, to which the Living Room was very well suited. The exhibition contained a home theatre, floor sensor demo (which was built into a game), EMFi demonstrator, a flower pot monitor demo, a smart wine bottle rack and an InfoCube demo. Visitors showed keen interest in all the various technologies, particularly the flower pot monitor demo with its capacity to monitor the well-being of the plant and adjust lights and curtains to achieve maximum growth. The exhibition lasted two days after which the equipment was transferred back to the Living Room.

Figure 9.1 The "e-home" stand at MindTrek 2001 exhibition showing the living area in the middle and the InfoCube demo to the right.

Activities around the Living Room -project provided valuable educational experiences for our group of young researchers, and experimentations with different kinds of hardware, networks and UIs offered many ideas for further development and improvement. The research group now came to view ubiquitous computing environments and user interfaces seem as the key factors in smart home design. The Living Room laboratory was in use until late 2002 when an opportunity arose to move to a new testing environment. The Living Room was dismantled and the hardware moved to the new location.

9.2 Findings From the Smart Home

The Smart Home laboratory was completed in late 2002 and has been in use ever since. Like the Living Room, the Smart Home apartment is used primarily for demonstrations, testing and also as a social space for department employees. During busier periods there are weekly visits to the Smart Home, by student groups, schoolchildren, exchange students and corporate visitors. It is in use daily and provides us with practical information on functionality and usability in everyday life. Students on the "Modern user interface electronics" post-graduate course have also participated in usability research and electronics design and have contributed new points of view to our knowledge. They have also been helpful in testing various UIs and writing reports.

Overall, it has been proven useful to have several different UIs from which users can control and monitor the home. The situation changed very much from the one UI-scenario in the Living Room, since now there were numerous choices. The most frequently used UI is

the tablet UI, which replaces bulky remote controls and offers users a unified way of using the home entertainment system. It displays the status of the home clearly and allows for easy and quick control of lighting and home appliances. Visitors to the Smart Home have also found it easy and quick to learn to use the UI without additional instructions, however its Finnish language text provided daunting for foreigners. Other UIs for controlling lighting (pushbuttons, touch panel) are good for their primary purpose and quick to access when needed. Speech control and a mobile phone UI again proved to be handier when moving around the apartment and mobility is required.

The Smart Home has proven that is possible to connect different kinds of (incompatible) networks, devices and user interfaces together to form a unified home infrastructure, and the value of such a system will continue to be proven in the future as more functionality and features are added. However, when the network infrastructure and possible applications were designed there were several practical issues that limited the implementation of a pervasive home network where everything would be connected, especially with regard to home appliances. Connecting existing home appliances to the home network varies from easy (coffee maker, motorised door, blinds, lights) to difficult (stove, microwave oven, A/V equipment). Devices that originally have no network interface or remote control functionality either must be taken apart and physically modified (costly, difficult or even impossible), or externally monitored with some kinds of sensors (easier but less reliable). In the latter case, for example, the temperature of a refrigerator could be monitored with an additional sensor or the status of the microwave oven (standby or in use) with a current consumption sensor. Sometimes the lack of a network connection does not matter, for example, remote control of the kitchen stove would serve little purpose as someone has to be present when cooking anyway and modern stoves already have automatic safety timers. However, in this case monitoring the temperature around the stove and movements of the person can prove more valuable information.

Networks in the Smart Home have allowed devices to be connected either wirelessly or with wired networks using a standardised connector. Even if the device and network configuration can be changed rather freely, the major challenge is reconfiguring the Home Controller and especially UIs. Adding a new device requires an XML description and possibly a rewrite of all UIs since certain new UI elements might be needed. Thus modifying the functions, UIs and Home Controller software requires some amount of manual work, making the process cumbersome and slow. A dynamic, self-configuring UI and a modular plug-and-play protocol would be required for a fully functional and adaptive commercial smart home network. Further development is also needed of protocols and the way that new devices are introduced into the environment. It is difficult to make flexible user interfaces for every device, especially if they can be removed and added frequently, which is why development on a service discovery protocol was started in conjunction with the LIPS project. Some networks could also benefit from being redesigned; the serial hub for example, can only communicate with one device at a time and can become flooded if too many messages are sent in succession. Major problems will result if the hub locks up all traffic to the Smart Home devices connected to it. The communication protocol also needs improved algorithms and greater privacy and error-correction methods. At present it does not have enough fault tolerance, and the wireless traffic is basically unencrypted.

The Home Controller has been very useful in bridging together different network types. An intelligent centralised gateway makes it relatively easy to combine different devices and networks, even when they are totally incompatible. Even with the limitations mentioned above, using different network technologies and connecting new devices has been made easier because of the upgradeable server software and the versatility of the PC platform. This is a major advance on the tabletop UI used in the Living Room, which lacked modular design and appropriate software interfaces.

Visitors often ask how much such a smart home system would cost, and there was also considerable interest in the tablet UI and its home theatre controls. Naturally it is difficult to answer questions on the cost of such a prototype system, but it is clear that people are very interested in such a system.

9.3 Findings From the eHome

The eHome project was a unique study that set out to discover how a smart home would function in everyday life and what kind of functionality it should and could offer its users. This practical study produced the kind of results that could not otherwise be gained from theoretical laboratory tests and it also taught the research team much about the practical issues around smart homes. It seems that the most desirable functions of a smart home are indeed the various user interfaces that allow greater flexible control of the home without increasing the amount of technology and complexity that lead to concerns over loss of control. The home should also contain learning and adaptive functions, which would gradually allow users to transfer certain functions of the home to the home controller. This paragraph summarises the major findings of the eHome project, with the exception of private or sensitive information and the omission of unpublished data.

By far the most valuable experiences from the eHome were those gained from the reports and experiences of the tenants; during their three-year occupation they provided the research group with a great deal of material to study and process. When the project was concluded and the eHome dismantled in 2005 user feedback was collected and analysed [Koskela04_1]. It was interesting to see how living in the eHome had changed the tenants' daily routines, how visitors to the eHome experienced it, and how the system performed as a whole. As mentioned in Chapter 5, data was collected from the tenants by a usability researcher from TUT (as a joint project, called Smart Home Usability and Living Experience), but activity logs, error logs and spontaneous user reports were also collected on a regular basis.

The couple living in the eHome apartment were a female of 25 years and a male of 26 and they moved into the apartment in late 2002. To the couple the home was a place where they spent most of their time, a place for relaxation and being together. They also enjoyed cooking and much of their time was spent in the kitchen. At the beginning of the eHome project the tenants were introduced to the UIs and functionality of the home, and they were able to start using it immediately. Initially they showed great interest in the TV UI, as it seemed a logical and familiar way of controlling the home. However, they found the mobile phone less interesting as it seemed an unusual place from where to control the home and because

they were unfamiliar with the particular model. The WWW-UI had a clear role from the outset as the main console from where to input the timer settings, preset modes and so on. Eventually, however, the situation was to change considerably; the mobile phone quickly became easily the most popular UI in the eHome. This was due to problems experienced with the TV UI that became apparent as it was being used on a daily basis, and it soon lost its appeal to the tenants. The PC in which it was running gave off a slight noise when turned on, which the users found disturbing, so they turned it off whenever it was not needed. This led to one particular problem with using the TV UI. To start the computer and load the software took considerable time, and led to decreased use of the TV UI. Other difficulties were caused by the infrared remote receiver, which required the remote control to be pointed precisely at it in order for commands to be received. Although this problem was solved later, it did not fully restore the confidence of the users in the TV UI. As the PC controlling the TV UI also functioned as a DVD player, it did receive some use, and controlling the lights to watch a movie worked as expected. However, the tenants preferred not to open the home control UI during a movie or when watching a favourite TV program.

The reasons for the surprising popularity of the mobile phone UI were its instant availability (the phone is always on), an intuitive UI (the eHome control applet was made using Nokia-style menus that were similar to the standard menus in the phone) and universal access (it could be used wherever there was cellular network coverage). Furthermore, the phone was easy to carry (it was physically smaller than the TV remote control) and it could be used to turn off all lights and equipment when desired. It did not have to be pointed in any particular direction when used and pressing a few buttons on the phone is usually much faster than turning on the laptop PC or TV for making a simple adjustment. The WWW-UI was primarily used for making more complex settings or supervising conditions, as it was too clumsy and slow to start up just to turn off a light or adjust window blinds. The WWW-UI was also rarely used for making adjustments to another room since the eHome apartment was too small for this function to be useful and both tenants usually shared the same room with light switches easy to reach. Users would default to manual control when not in the same room as the laptop, and as a result, in these cases they made limited use of the WWW-UI.

Table 9.1 below summarises the properties and findings for eHome UIs.

Table 9.1 Summary of eHome UIs.

	Phone	**TV**	**Web**	**Manual**
Pros	Always on, available, familiar	Big screen, familiar control style	Touch screen, customisation, intuitive UI	Familiar controls, physical
Cons	Expenses, dependent on network coverage	Shortcomings of infrared controls, loud	Slow start-up, dependent on the computer	Very limited functions available

Table 9.1 Summary of eHome UIs.

	Phone	TV	Web	Manual
Mobility	Excellent	Limited, range for remote control a few metres	Inside the apartment, limited battery life for laptop	None
Ease of use	Easy if phone is familiar	Easy, the same as using the TV	Medium, uses proprietary icons and touch screen interface	Very easy, push-buttons and natural UIs
Popularity	3-4 times per day	2-4 hours per day of TV usage	Laptop on most of the time, heavy usage	Used most of the time

The tenants in the eHome showed great concern for safety and energy consumption. They wanted to ensure that all unnecessary appliances were turned off (even standby-mode was undesirable) and devices were sometimes unplugged. They were therefore pleased that they could monitor and control appliances and lights in the home, either from the WWW-UI or remotely from the mobile phone. Light switches in the hallway were also programmed to turn all lights off at the press of a button, and the tenants made use of this whenever they went out. A feature that the tenants wanted to have, but one that would have been very difficult to implement, was to use the mobile phone for transferring data and files from home to work and vice versa. Though this would have allowed them to seamlessly take their work with them, it would also have meant leaving their home computer switched on all day, something they did not wish to do.

Many visitors to the eHome had learned in advance that the apartment was in some way different and thus had various preconceived ideas about what to expect. There were people afraid even to enter, thinking that they might accidentally break something or that the "intelligence" in the home would somehow cause them discomfort. Others were enthusiastic and eagerly tried out the different functions and UIs. The mobile phone UI was considered "cool" by friends and co-workers, and it was always demonstrated to people who were curious. Guests who stayed overnight quickly grew accustomed to the light controls, but young children were given a night lamp to prevent them accidentally turning on all lights in the house in the night. Obviously, a need existed for a more intuitive interface for lighting control, although people commonly need time before learning which switches control particular lights when entering any unfamiliar space (such as a hotel room).

At the beginning of the testing period, the tenants had understandable reservations about the system and its reliability. It took several weeks for them to get used to using the devices and learning how to operate the various user interfaces. New UIs and functionality were gradually introduced to the eHome under controlled conditions. Whenever a new device or function was introduced, the same learning process was repeated and user feedback was collected. However, when there were problems it could take some time for the tenants to regain trust in the system. For example, when timer settings and user profiles were lost during an update of the Home Controller software, there was a considerable delay before the

tenants started using it again. There were also other ways in which the eHome control system affected the users: there were interesting changes in their daily routines and lifestyle. Timer options, group controls and remote control became increasingly popular during the course of the project, and tenants soon realised that they had grown pleasantly accustomed to the system. For example in the evening, when the lights were programmed to turn off at 11 pm, the tenants reacted by registering that it was getting dark and time for bed. In the morning, the timer was set to waken them by opening the blinds slowly turning on the bedroom lights. After a few minutes the blinds closed again, allowing the tenants to go and take a shower. The tenants soon found this way of waking up much more pleasant than a noisy alarm clock.

The eHome system ran continuously for three years, and the infrastructure worked reasonably well throughout the experiment. Apart from a few blown fuses (caused by a broken light dimmer) and a broken computer power supply, the system required almost no attention from tenants or researchers. Devices were added during the course of the project and some were modified (for example, the TV UI), but otherwise there were no major changes. The eHome software, however, encountered a few problems. As is common with prototype software, there was downtime caused by updates, bugs and network failures. Depending on the problem, it might have meant that some of the UIs were unavailable, in which case the tenants temporarily stopped making more complex adjustments. Such faults can be very difficult for users to debug, and their cause may be difficult to determine. Furthermore, smart home technology cannot be repaired or diagnosed like other household problems, making it especially difficult for users to cope with sudden faults. More serious faults however might have rendered the entire control system inoperable, forcing users to default to the manual controls. Initially there were major problems with the ADSL connection to the apartment, but the problem was later identified as a faulty modem. The lack of an Internet connection made the phone UI inoperable and also cut off remote connections to the server. This did not affect connections within the home, so the Home Controller and local UIs continued to function normally. Whatever the fault or the case, the logfile that the Home Controller software created was of very useful in debugging problems and for monitoring user activity. The logfile contained details of every adjustment, event and fault, as well as a timestamp. It thus provided valuable information on user activity and UI functionality.

Since the eHome apartment was rather small, there were situations in which the possible gains from a smart home control system were not fully realised. For example, it was not very difficult to check if the apartment lights were still on or to walk to the light switches and adjust the lighting. The relatively limited number of users and age groups made it difficult to conduct serious multi-user research. Mobile UIs were thus not very important either, even if the tenants would have preferred to use the TV remote control for other purposes, such as adjusting lights and blinds. The remote could be pointed at a specific device and could be used to directly control it, which would be faster and easier than doing this from a graphical UI (in a similar way as in [Ritala03_2]). Another improvement would have involved the dimmable halogen lights in the hallway and kitchen, which in the eHome could only be controlled via graphical UIs. Wall pushbuttons could not be used as they were wired to control 240 Volt lights only (through the LINET network), resulting in problems if the Home Controller was out of operation for some reason. Probably the big-

gest improvement to the eHome, which was suggested by the tenants, was an adaptive home control system that would actually make the home smart. The home control system could make observations about the actions of the users and make decisions and adjustments on the basis of this learned data.

A thorough report on the findings from the eHome project was can be found in Tiiu Koskela's Master's thesis [Koskela03]. According to the author of the thesis, there are two important requirements to be considered when smart home UIs are being designed. These requirements can be expressed as "right here, right now", with the first element indicating that the UI must be constantly in stand by mode, and the second, that it should be available for use immediately. Furthermore, tasks executed by the UI should be made using as few actions as possible, for example, using shortcuts or customised presets. The second requirement is that UIs should be available wherever the users happen to be, thus pointing towards context-aware control and mobile UIs. A final issue is to enable users to overcome their distrust of new technology and applications. If trust has to won time and again, it will severely undermine attempts to create the safe and relaxing atmosphere that a smart home should offer. This relates to the broader objective that seeks to ensure that users remain in control of events in the home, whether these are automated tasks or learned behaviour.

9.4 Discussion

Smart Home projects at TUT have shown that the use of multiple UIs can provide intuitive, flexible ways for users to interact with the environment without the need for greater effort. Since the tenants in the eHome are a young student couple, it is clear that more research is needed on different age groups and different family units. The next step in smart home research would be to expand the research target group to include families with children. Furthermore, elderly people would benefit greatly from smart homes since the technology would enable them to stay in their homes longer without support from the community or relatives. The same technology can be adapted to each of these user groups, although user interfaces probably would require changes so they would be more suitable for the target group. Another issue often overlooked is the influence of national cultures on the acceptability of smart home solutions. For example, in Asia the definition of a home probably is the same as in Europe but its function may be largely different; home values and priorities in certain cultures might diverge from those considered in the present work. The home can be an environment where many families and generations live together, where people constantly come and go and where walls do not necessarily mark the borders of what is considered a home. In this respect, the benefits of an adaptive learning home control system would also prove important.

TUT smart home research set out to discover how smart spaces can be built and designed and what options there are for users to control smart environments. From the outset the contribution has been a practical approach to research; instead of simulating and speculating the research group has constructed devices, built test environments and conducted tests. Research contribution from TUT research projects has been summarised in the list below:

- Functional prototypes that can be used, tested and modified
- A total of three functional test environments
- Home network infrastructure, both wired and wireless
- Communication protocols suitable for smart homes
- Modular home control middleware
- Multiple user interfaces for smart homes
- Learning and adaptive control software
- User test results from both laboratory and long-term tests

However, in spite of all this research there are a great number of questions that still remain unanswered and research directions that would be interesting to explore. For example, the commercial aspect has been practically overlooked, devices and applications have not been commercially taken up, nor have they been designed to be mass produced in any fashion. The only exception has been the Blue Post [Kaila05_3], which was designed directly for a commercial purpose. From a researcher's point of view it can be difficult to envision the requirements and future of the commercial market, which is why a commercial partner could have brought more insight into smart home research. In addition to hardware and home appliances there is also the (third party) service aspect, which could provide a valuable connection to services located outside the home. Another regrettable issue was the premature ending of the eHome project; it would have been interesting to continue the experiment with different user groups and with an upgraded smart home system. This would have enabled researchers to gather data from a larger group of users as well as further develop the user interfaces and control software.

Using Frances Aldrich's classification of smart homes [Aldrich03] presented in Chapter 2 TUT smart home projects can be classified to fit the second, third and fourth category:

- Homes with intelligent communicating objects (intelligent appliances and objects are able to communicate with each other and exchange information) - **The Living Room**
- Connected homes (homes with both internal and external networks, making them and their services accessible from inside and outside) - **The eHome**
- Learning homes (homes that record and adapt to behavioural patterns of their users, control the devices accordingly and predict the user's future actions) - **The Smart Home**

Table 9.2 summarises the research goals and contribution of TUT smart home projects, and it also presents short comments related to each project.

Table 9.2 Summary of requirements and findings from TUT research projects.

Project	Research Goals	Contribution	Findings
Living Room	• Testing space for smart home infrastructure • Creating a relaxing environment • User activation • Centralised control	• A smart home laboratory with controllable devices • A relaxing and pleasant environment • First prototypes for smart home hardware and software	• Centralised UI inadequate • Other ways of control required • Implemented networks were too primitive and unreliable
Smart Home	• Network and device interoperability • Expanding research to a complete apartment • New UIs	• The Smart Home laboratory • Home Controller middleware • EPIS service discovery protocol •	• Distributed UIs were useful • Home middleware is essential • More user testing is required
eHome	• Getting results from real life usage • Conducting user studies • Multiple UIs • Security for users	• eHome UIs • Usability test reports • Three years of usage data • Experiences used to improve the Smart Home	• Project was very educational • Adaptive control software was requested • System stability and reliability could be improved

9.5 Summary

Based on these experiences, it can be concluded that connecting home appliances and devices together can achieve new levels of control and communication. Combining different kinds of networks and protocols can be laborious, and may give rise to new problems, but the final outcome will be worth wile when the full potential of the networked space is realised. The result will be innovative and easy ways to control smart spaces, homes and devices. A centralised gateway that binds various network technologies together will enable the building of effective and flexible intelligent environments, even if the devices and networks themselves are incompatible. While awaiting the advent of such a universal connection method, we need to adapt existing solutions and use them to their full potential. However, since there are no compatible devices on the market, it may be a long wait before smart homes become commonplace.

10. Analysis

This chapter discusses the current and future state of smart homes, what has prevented the smart home from becoming more popular than it is, and what could be done to make it a more attractive option than the traditional home. Discussion of these topics is then followed by some concluding remarks.

10.1 Reasons Why Smart Homes Still Are Almost Nonexistent

Modern apartment buildings are not greatly different from their 1970s counterparts, the basic layout and functions having remained much the same. Windows, doors, walls, bathrooms and so on have changed little and function in the same way as they have done for decades. Naturally, there have been certain changes in the form of new materials and new kinds of cabling. Home networks are routinely used and installed, but rarely does the utilisation of state-of-the-art technology extend beyond such innovation. The homes of IT-millionaires, office buildings and concept homes usually contain a great deal more technology, mostly related to building automation, communication, entertainment and security. Smart homes, in the general sense, are largely nonexistent. This prompts the question as to why the smart home has failed to become accepted by the wider public, despite the technological advances starting thirty years ago when the first smart home made its appearance.

The primary motivation for end users to invest in new technology is the balance between necessity and appeal and also cost [TATU04]. New technologies may be intriguing, but if the application itself is considered unnecessary or too expensive, consumers will hold back. The cost of the latest smart home technology remains high and the prospect of installing potentially incompatible and marginally useful hardware into a home makes it an unattractive investment. Another hindrance to the wider acceptance of the smart home is the push by the technology industries to persuade people to buy their ever more sophisticated products [Aldrich03]. Too little emphasis is placed on usability and user-friendliness, making technology seem foreign and unfamiliar. Instead, the focus should be on user-friendliness and usability as well as usefulness and compatibility. Developers need to remember that smart home technology should not greatly alter the atmosphere of the home, and nor should it detract from home comfort or attempt to replace the essential values of home life. Ultimately the general public have very little understanding of smart homes and, it seems, very little interest in ownership.

A study by Nokia [Nokia07] bears out the above observations on the adaptation of smart home technology. The study attributes this public reluctance to the absence of any common protocol and a lack of compatibility among devices and networks, combined with high prices. Security and privacy also give cause for concern, especially if a home is filled with sensors and cameras that can gather rather personal information on the occupants. Many of today's appliances and office devices contain network functionality rendering them as vulnerable to attack as any other networked equipment. Printers, routers, game

consoles, WLAN gadgets, etc. all have web servers or remote administration services running, and these embedded software modules are seldom upgradeable or fully secure [ProSys07]. When such equipment is permanently connected to the Internet there are serious security and privacy risks, often unknown to users. Most people are intimidated by the spectre of a "Big Brother" in the home and therefore it is important that infrastructures are secure and totally isolated from the outside world.

Another important factor is the work and resources that have to be committed when retrofitting smart home technology into old buildings. The majority of smart home installations are likely to be in older buildings, involving additional costs for the user. Modern homes currently have Internet access, PCs or similar terminal equipment, mobile communication devices and certain external services that connect to the home (cable television, online services, etc.). There are, however, numerous features and devices that are still lacking, in the form of ad-hoc short-range wireless communication (i.e. sensor networks), indoor positioning, adaptive UIs and suitable sensor matrices.

Preconceptions and image factors, combined with general mistrust of new technology, can also be major obstacles to the wider public acceptance of smart homes [Leppänen03]. The smart home is sometimes perceived as an environment in which humans become passive and indolent, their daily lives controlled and dominated by the devices that surround them. Other people reject smart homes on the grounds that they will be made to look and feel stupid by allowing technology to take over their daily activities and chores. Perhaps the very term Smart Home and its connotations need to be reviewed so they convey a more exciting and user-empowering image. This could be accomplished through smart home interest groups and active promotion by the industry.

10.2 Future Directions

As with most technological innovations, there is the inevitable "chicken and egg" problem in the early stages of development. Initially, the cost of new technology can be very high because of low demand and high development investment, with the result that very few people can actually afford the technology. Furthermore, when a new standard or feature emerges it needs a lot of support services and applications or it will quickly disappear from the market. People will not buy a smart home system that supports only a few sensors and devices, and companies will not develop devices for a smart home system which nobody uses. Thus we are faced with a situation where there are no applications because of a lack of compatible products, and there are no compatible products being developed because there is no application to use with them. This also makes smart home research challenging because there exist relatively few installations and complete smart homes to allow larger scale studies to be conducted [Mäyrä05]. Studies must therefore be performed in laboratories or with mock-up equipment, making it even more difficult to test and develop real-life smart home technology. Ultimately, there will perhaps be no single dominating de facto home communication standard, but many different ones will be supported instead. This also makes economic sense since it would allow every application to be designed around a suitable infrastructure.

Currently in smart home development there seems to be no "killer application" to make the technology more appealing, and while the other benefits of smart homes (as described in Chapter 3) are substantial, they are either unknown to the general public or not attractive enough to justify the investment required. A rapidly growing elderly population clearly points to the need for innovation and development in the fields of healthcare and assisted living at home and already society is investing huge sums to meet this burgeoning growth in demand. Smart home development could thus capitalise on these healthcare issues by providing savings to the social services through helping the elderly and infirm to remain longer in their own homes and thus avoiding the need for nursing care. Present smart home applications are mostly being developed by companies in the electronic, medical and telecommunications industry and thus they do not necessarily cooperate on a large scale with the construction industry. On closer inspection, there are in fact a surprising number of firms and organisations with an interest in smart home development [Himanen03]. Construction companies build according to established production models, prioritising efficiency, cost and workforce utilisation. Furniture and interior designers must consider aesthetic and practical issues of living, while also following current trends in modern design. White and brown goods are supplied by the electrical and electronics industry, the former attempting to save people time by assisting with everyday chores and work, while the latter seeks new ways to spend leisure time. In addition, sociologists and social-workers, whose working places are other people's homes, are involved with the welfare, mental health and comfort of their clients. Telecommunication companies are responsible for bringing multimedia, video-on-demand and broadband networks into the home, enhancing connectivity and communication. All these various interest groups make are examples of how smart home development is really a huge multidisciplinary endeavour, requiring scientific and practical input from numerous fields.

Other aspects related to smart home development that might require change are public attitudes and assumptions about new technologies. The status of current "cutting edge" technology does little to help in this respect, since both software and hardware are released without sufficient testing or verification. Many users are already accustomed to installing updates to software or flashing new firmware soon after a new product is removed from its packaging because it will often not work with the pre-installed version. People will hardly be motivated to buy such products if they must perform these tasks each time they buy a device for their homes. Smart home devices and technology should be based on proven, reliable technology and also presented to users as such.

New technology should be introduced into peoples' homes gradually rather than suddenly or on a large scale [Leppänen03]. This will help users to become accustomed to the new functions and UIs and thus cope better with the devices in their daily lives. In the case of retrofitting old buildings, this would be an inevitable consequence since people would first choose to purchase a few devices, install the basic infrastructure and acquire more devices and applications later as their needs become clearer. Since smart homes would ideally be tailored for each application and scenario it is important, that the requirements and wishes of the customer are identified clearly when the system is being planned. This helps to ensure that the smart home will meet the particular needs of the customer instead of being a generic pre-specified package. It is forecast that future living and homes will be modular [Rönkä03, Leppänen03], with user-configurable options when the home is purchased, in

the same way that automobiles are today. This allows buyers to select the rooms, materials and floor-plan they prefer, whether it is a traditional cosy home with a garden, a functional urban dwelling for modern living or a luxurious villa full of modern conveniences. Similarly, smart home technology can be modular and customisable, to make it suitable for a variety of scenarios and situations. This also allows the construction of concept homes, which are larger units designed around a common theme. Over the passage of time, it would be possible to make changes and adapt the home to suit a new lifestyle.

10.3 Final Thoughts

As stated in the introduction, a major obstacle to smart home development is incompatibility and the problems of complicated UIs, making it difficult to integrate technology and human factors. The results and experience gained from projects described in this thesis provide a possible solution to this problem. The solution can be divided into two parts:

Compatibility problems can be alleviated by bridging current networks and protocols together with middleware and by selecting the most appropriate technology for each application. Technologies such as DLNA can enable connection of different kinds of devices, allowing them to share information and controls. Other kinds of compatibility problems (e.g. physical and electrical) can be overcome by using adapters and converters, but if the content or information is completely of a different kind it can be a strenuous effort to create a system that would understand this information and be able to convert it into a common format. For example, it would be a rather simple task to convert temperature readings from different sensors or different video signals into a common format, but in the case of contextual information (e.g. the user is eating, the TV is broadcasting news) knowledge about the user's tasks it would be a much more complex case.

Compatibility and standardisation are closely related, but there are also several issues that standardisation cannot (and possibly should not) affect. For example, social and psychological issues vary greatly between users and user groups and could probably not be alleviated this way. One further thing of note is that standards can be short-lived, and if the IT world is any indication, there is a steady flow of new technologies on to the market to replace the existing technologies which quickly seem outdated and limited. IT standards typically last only a few years (there are exceptions, for example the 3.5" floppy disk which has been an IT standard for over 20 years) and newer standards are not necessarily backwards compatible. Furthermore, in spite of international standardisation efforts, cooperation and open forums unexpected standards can still emerge and become widely accepted by the industry, even if they were not originally intended to be so. It is, however, likely that eventually any standard becomes obsolete or is replaced by an improved version. This means that the smart home system of the future must be adaptive and modular and be able to accept often radical changes and new technologies.

The other problem, caused by poorly designed devices and UIs, is not correctable with modularity, home networking or extra software. Instead, the change should take place at a significantly earlier stage, i.e. already during the design phase. Improving usability, making it easier to connect and use networked devices and dispelling user irritation with tech-

nology, can be achieved by introducing good user interfaces. Confusing button layouts, misleading labels, inconsistent terminology, for example, could theoretically be avoided by using standardised intuitive UI models. Bringing UIs together within a single location will help to promote the creation of common norms and standards, making it easier to manage a myriad of devices: this could, of course, also be counter-productive if the devices are poorly designed. Allowing devices to be controlled from the UI of another device can achieve the same result, improving interoperability and adding flexibility. As the findings in Chapter 9 demonstrate, an optimum situation is reached when users have many interfaces to choose from. This means they can choose the most suitable UI for any given situation, whether it is in the living room, in the backyard or away from home. This also presents a possible solution for improving social and informational compatibility, as this is often a personal and cultural issue which is also easily affected by other people around us. Finally, as a home user interface, the mobile phone is becoming an ever more suitable control device and may eventually become the most popular smart home UI as its features and connections improve.

In order to provide an answer to the research question raised in Chapter 1, for users to fully benefit from smart home technology a smart home should:

- Provide sufficient benefits for users
- Be modular and adaptive, with room for future expansion and modification
- Be easy to install and maintain (or include a maintenance service)
- Provide improved usability and controllability through appropriate UIs
- Allow the user to be in control and to dictate higher-level system behaviour

Moreover, if compatibility problems are the cause of frustration and confusion among users, it is logical to assume that mitigating this problem would already be a large step towards increased usability and reduced complexity.

10.4 Conclusion

Today it is clear that earlier forecasts for a Ubiquitous Computing revolution have been over optimistic: while we are surrounded by a vast array of computational devices, these are still rather independent with only limited capacity to share information or resources among each other. However, computers are becoming more inconspicuous so that nowadays most of us are often oblivious of the role of embedded computers and other electronics in our daily routines. Computing has become so commonplace and familiar that we no longer notice it, and if would be aware of the number of devices that include a processor we would certainly be surprised.

Predicting the future is closely related to the subject of smart homes, and a popular question asked by the media, guests and students is when will such homes become commonplace. Ten years ago we would probably have suggested ten years but, unfortunately, this reply is still true today. It would seem that Osmo A. Wiio's law, stating that "the near future is overestimated and the far future underestimated" still applies [Wiio78], despite the marketing fanfare surrounding technological innovations. Another popular quote regarding in-

novations and the future is by Petri Kotro, CEO of Valkeus Interactive. He observes that "engineers are almighty" and it is possible to build almost everything, but it is much harder to invent something that is truly usable and useful.

Smart home research has made huge progress during the author's ten years of involvement in the field. However, there is still a long way to go before most of us can sit back and relax in our smart homes. However, interesting times lie ahead and the smart home is assured of a place in this future.

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